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ARL 175

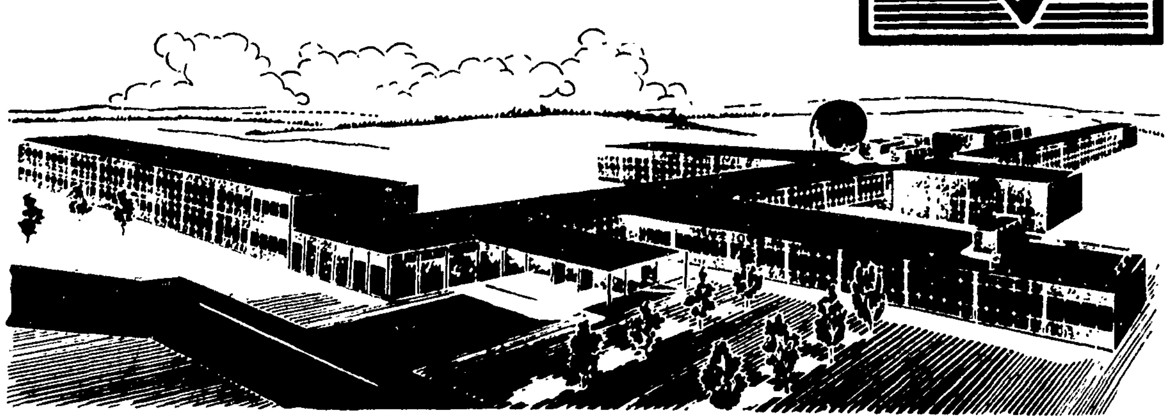
HIGH SPEED SHUTTER SYSTEM

WILLIAM O. REED

THE RAULAND CORPORATION
CHICAGO, ILLINOIS

DECEMBER 1961

AERONAUTICAL RESEARCH LABORATORY
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE



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CONTRACT AF 33(616)-2095
PROJECT 7065
TASK 70824

AERONAUTICAL RESEARCH LABORATORY
OFFICE OF AEROSPACE RESEARCH
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO

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FOREWORD

This technical report was prepared by the Research Laboratory of the Rauland Corporation of Chicago, Illinois on Contract No. AF 33(616)-2095 under Project 7065, "Research on Techniques in Aeromechanics" and Task 70824, "Interferometric Method of Flow Study".

This work was initiated by Mr. Ben B. Johnstone who was also the task scientist. The project was under the guidance of Dr. John E. Clemens, Chief of the Engineering Physics Branch.

This report was not published at an earlier date because of previous classification.

Acknowledgment is given to the following personnel of the Rauland Corporation's Research Laboratory which participated in the development of the High Speed Shutter Tube:

The bulk of the work was performed by William O. Reed, the Project Engineer, with the help of Herman H. Jordan, Chief Technical Assistant, and Raymond Armstrong, Glass Engineer.

Considerable assistance was rendered by Theo. S. Noskowicz in testing the tubes and taking photographic recordings.

Appreciation is entended to Mrs. Anne Jones of the Plasma Physics Research Branch of ARL for typing the manuscript.

ABSTRACT

A high speed camera system capable of recording 16 pictures, each exposed to the light from the object being viewed for 3×10^{-7} to 3×10^{-6} seconds, was developed during the contract period. The system is capable of doing this with an overall light gain so that considerably less light need illuminate the object under study than is required by high speed camera systems based on other physical laws. The experimental evidence furnished shows that photographic negatives having densities of 0.5 can be achieved with 1 microsecond exposure and 200 foot-candles illumination incident on the photocathode (150 watt projection lamp at 110 V) with readily available photographic film and camera optics.

The essential shutter element in the camera system is an image converter tube which can amplify the light by factors of over 25. The photoelectrons emitted by the light from the object under study are controlled in their accelerated flight to the fluorescent screen by a mesh grid. The grid receives positive voltage pulses of 65 volts amplitude from the circuity developed for the purpose. These pulses are synchronized with the phenomenon being observed and are controllable in width and spacing by the circuitry. The use of 20 KV final anode potential ensures high efficiency in the conversion of electron energy into luminous energy from the fluorescent screen. The 16 separated pictures are obtained by synchronizing the deflection currents through the yoke with the grid shutter pulses such that while the shutter is open the sweep is held steady on the screen, and when the shutter is closed (grid negative), the current through the yoke changes by the right amount to have the picture in a new position when the grid again becomes positive. A certain amount of jitter caused by intercoupling of the circuits and by response time of the deflection yoke limits the resolution of the dynamic picture to 16 lines per mm.

The circuitry provides for the following adjustments:

16 successive pictures can be spaced 2, 5, or 10 microseconds apart.

The shutter pulse unblanks the photocathode of the shutter tube for each picture with a rise time of approximately 0.05 microseconds and with variable delay of 1-3 microseconds. Synchronization of the scan is obtained from either single or continuous triggers. An adjustable delay between the input trigger and the first picture is also available.

Auxiliary equipment includes a magnetic blanking yoke, associated circuitry and a synchronized pulser for operating a photoflash lamp.

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INTRODUCTION

HISTORICAL REVIEW

The study and recording of motion which occurs in very short periods of time requires special processes and mechanisms which exceed the requirements of amatuer and professional photography. Many ingenious mechanically-driven cameras have been devised in the past as the demand for higher speed photography was increased through the desire for better knowledge of a bullet's flight path, of the behavior of explosives, of the vibrations occurring in rotating machinery, and of jet turbine engines (1). Cameras capable of recording many pictures per second for several seconds are the Wollensak Fastax (14,000 frames per second, maximum) and the Kodak High Speed Camera (3200 frames per second, maximum). Mechanical limitation of cameras of this type expose the film for several microseconds and their light-gathering power is low, because they use the available light inefficiently.

Cameras using mirrors revolving at high speed to reflect the light onto stationary film with microsecond timing have been devised. But these cameras are generally useful only for streak photography such as might be desired in the study of the luminous shock wave front from an explosion. They record at speeds up to 4,000 meters per second. These cameras also have a small aperture (the mirror must be small to be revolved so fast) and so require enormous amounts of light. Drum cameras with the film mounted on a revolving drum also have been made for recording high speed phenomena (up to 200 meters per second recording speed).

A camera using a Kerr cell[2] is probably one of the fastest and oldest means of "stopping" motion with a shutter which operates in a millionth of a second or less. (2) It is readily possible with the pulse techniques available today to make the electrical "shutter" potential pulse shorter than 10^{-8} seconds. The most familiar example of the use of this Kerr cell shutter is the camera used in photographing an atomic bomb explosion. But, as in the other types of high speed camera which have been described, considerable light loss results from the use of this Kerr type shutter, partly due to very high light absorption and partly due to the limited angle of the light beam transmitted.

Recently developed high speed shutter system which exceeds any rotating device in speed and excels the Kerr cell by virtue of having light amplification properties employ image converter tubes (3, 4, 5). In recent years it has been used only for making single exposures or for streak photography in which the focused electron image from the photocathode is swept linearly across the fluorescent screen (writing speeds 100 times faster than can be attained with a mirror camera have been obtained).(3) Its operation as a light shutter depends upon the control of the passage of electrons emitted from a photoemissive surface (the cathode) by a grid voltage or by the final anode voltage to which the photoelectrons are accelerated. Ordinarily, the controlling voltage is maintained at a low or slightly negative voltage with respect to the voltage on the photocathode until an exposure is desired at which time an appropriate pulse voltage is applied to the control electrode, and the photoelectrons are accelerated and focused onto the fluorescent screen. The light flux from the screen is then photographed to make a permanent film record of the high speed event.

Since 1953 suggestions were made to increase the usefulness of the image converter shutter tube by displacing a small image on the fluorescent screen by discrete steps. Jenkins & Chippendale (5) say "It will be probably possible with future types of tubes having larger screens to give the image up to 25 different positions on the screen, enabling a sequence of 25 pictures to be taken by a simple shot".

In a recent German paper (6) there is a report on a tube and equipment with which "according to the present state of development it is possible to present a sequence of 4 pictures".

In the U.S.A. the problem was attacked by Hett Associates (7) who, using a magnetically focused Mullard image converter tube, obtained displaced images in one direction only.

OBJECTIVES OF THE PRESENT CONTRACT

The original purpose of this investigation was to design and construct a system capable of taking successive microsecond pictures with the light from a Mach-Zender interferometer at the Aeronautical Research Laboratory which is arranged to analyze the change in density of the air flow past turbine blades by the amount of the fringe shift from the undisturbed fringe pattern. It was also desired to use this equipment for tests using Schlieren techniques(8). The light available was just sufficient to directly record on photographic film using a pulsed Hg light source (5-microsecond pulse length which did not adequately "stop" the action; also the source wavelength spectrum changed during the pulsing owing to pressure changes in the source). Therefore, a light gain of at least a factor of 5 was desired to use a one-microsecond shutter open time, assuming the unpulsed light source would give the same illumination as the 5 microsecond pulsed light.

Other applications for the system would be the study of explosions, jet, turbulences in air-foils, projectile flight, electrical discharges, etc., as mentioned in the references.

The high-speed shutter camera system to be developed by the Rauland Corporation under Contract AF 33(616)-2095 was to be designed to have an overall light gain as well as to record multiple pictures with an exposure time of each picture of less than one microsecond with the time between pictures as short as two microseconds. The critical component in the system which supplies the light gain and the shutter control is an image converter, especially designed for the purpose by the Rauland Corporation. The image converter shutter tube has the same capabilities of short exposure times (less than 10^{-8} seconds) as the Kerr cell type of shutter with the added advantages of light gain. Furthermore, sixteen pictures are placed in a separated, square array on a single fluorescent screen so the exposure of a single film to the light emitted by the screen will record the 16 pictures thus, eliminating the mechanical difficulties encountered with rapidly rotating parts. If desired, however, the sequence of 16 pictures may be repeated a few thousand times a second. Many combinations of variable shutter opening time, variable time between pictures and variable size of the pictures are also possible.

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SECTION II
RESULTS OF THE WORK

HIGH SPEED SHUTTER TUBE AND SYSTEM PERFORMANCE

The tube developed at the Hauland Corporation is focused electrostatically by one main lens and two or three supplementary electrostatic lenses. This arrangement of the lens system provides for a variable focal length so that the size of the image on the screen may be varied while maintaining good definition. Variation of $1\frac{1}{2}$:1 on a linear dimension can be obtained if the size of the image on the photocathode is under 2 cm. With larger images the change in magnification consistent with good resolution is reduced. One special feature of the tube is that the image has only very slight pincushion distortion even though the photocathode and screen surfaces are flat. Low voltage ($\approx$40 volts) pulses are sufficient for gating the tube "on" owing to the use of a 200 line mesh grid close to the photocathode. Standard video amplifiers may thus be used for supplying the shutter pulses. For applications requiring better definition and in which the appearance of the mesh bars may be objectionable, although in most tubes the bars are not in focus at the same voltage as the cathode, an electrode structure omitting the mesh control grid has been designed. This latter tube requires 350 volt shutter pulses on the control electrode and the pulsed picture definition is more critically dependent on the shape of the shutter pulse than is the picture in the mesh grid tube. Both of these constructions represent an advance over the ME 1201 B converter tube which requires 3 KV pulse voltages (- and +) applied to the cathode and to the anode - the grid being held at ground potential(3,4,5). Also, these English tubes are focused electromagnetically and are thus subject to S-bend distortion and to poor resolution unless the image on the fluorescent screen is more than $2\frac{1}{2}$ times as large as that at the photocathode, a result which leads to a considerable loss in brightness from that which could be obtained if the fluorescent image were smaller than the photocathode image.

The step function sweeps which successively move the picture to the 16 fixed positions on the fluorescent screen are supplied by the fields of an electromagnetic deflection yoke. Electromagnetic deflection was chosen because the deflection of relatively large cross-sectional areas of electron beams can be obtained with little distortion by E. M. deflection whereas it is difficult to design electrostatic deflection systems which don't distort even small cross-sectional area beams.

The resolution of the tubes made under this contract varies from 7 line pairs per millimeter to 20 line pairs per millimeter under DC test conditions. Under pulse operating conditions a maximum resolution of 15(N1) line pairs per millimeter has been attained. The resolution depends largely on the image-object ratio desired, on the photocathode area which is used, on the extent to which interfering fields (E.M. or E.S.) are prevented from entering the focusing electrode system, and on the tube construction. In pulse operation the change in focus due to cathode resistance drop and the focusing of the light optics as well as sweep jitter are also sources of blurring lower resolution.

Figures 1 through 17 illustrate the performance of the shutter system under different operating conditions. The legend under each photograph sets out the operating condition and discusses the particulars of each test. The resolution data given refer to the image on the fluorescent screen, and whenever practical the tube image has been magnified in the camera to avoid reduction of resolution as a result of incomplete focusing of camera. All these photographs are 1:1 prints of the negatives.

Tube Types

Three general tube sizes were constructed. Two of the sizes were restricted to a maximum diameter of two inches at the cathode and because of the largest standard yoke (inside diameter 2-3/16 inches) had to slip over this end of the tube. Precision-bore 7052 glass tubing (1.900 inches i.d.) was used since its use simplified the precise mounting of the focusing electrodes (Section III). The fluorescent screen end of one size (Figure 1) was 6-½ inch useful diameter and had two post-acceleration rings including the aluminized fluorescent screen. The minimum fluorescent image size to photocathode object size ratio which could be attained with reasonable resolution was four/thirds. Flux gains of a factor of 20 at 20 KV final anode voltage were measured when the photocathode had a sensitivity of 22 ua/lumen.

The fluorescent screen diameter of the more recent size (Figure 2) is 3-1/8 inches, and has only one post-acceleration ring which is connected to the aluminum film. Thus, the screen is much nearer to the main lens and a 17 inch tube results in an image-to-object ratio of one-half. With this smaller tube having a photocathode sensitivity in the neighborhood of 30 ua/lumen, light flux density gains of approximately 33 were obtained by measuring with a Macbeth type photometer the brightness of the fluorescent image and the illumination at the photocathode. The tungsten light source was operated at the color temperature of approximately 2870°K. Further reduction of the image-object ratio would require a substantial increase in the overall length of the tube inasmuch as the distance from the main lens to the screen is as short as it can be with the present yoke design (the yoke is 3 inches long and its field extends in appreciable amount for another 1½ inches); a shorter yoke and magnetic shielding of the main lens would allow a proportionately large decrease in the distance between the main lens and the fluorescent screen.

Astigmatism

It was expected that precise mounting of the electrodes would greatly reduce the astigmatism (difference in focus voltages for optimum horizontal and, or, vertical focus) present in the lathe-mounted tubes. Therefore, a third tube size (Figure 3) was designed to permit the most precise mounting of the focusing electrodes possible. Whereas, the focusing electrodes of the other two types were mounted to Kovar buttons sealed through the precision glass tubing (buttons on diameter precise to only about .005 inches and alignment checked while rotating the assembly in a glass lathe), the focusing electrodes of the third tube are held in alignment on a precision jig to within .0003 and glass pillars are sealed to rigid mounting tabs on the electrodes. The reduction in astigmatism in the new design was not marked, however, and it was subsequently discovered that the relay rack on which the tube and associated power supplies were mounted for preliminary DC testing had strong residual DC magnetic fields which were penetrating the magnetic shields as well as entering the tube through the ends. The use of .060 inch thick mu-metal shields extending beyond the ends of the tubes greatly decreased the

astigmatism in most of the tubes. The astigmatism again became a problem when testing the tubes dynamically. Residual DC flux from the deflection yoke and from the off-centering, "blanking" yoke was determined to be a partial cause of the added astigmatism. The astigmatism has been lessened but not entirely eliminated at the present time.

The precision jig mounted electrodes (2.100 inches i.d.) require 3-5/16 inches O.D. glass tubing for proper clearance of the 3 pillar glass supporting rods which hold the electrodes in alignment. Therefore, a standard yoke assembly cannot be used. However, it is possible to pre-assemble the yoke coils and to just barely interleave the laminations so that the yoke can be assembled on the reduced neck diameter provided for the purpose by simply pushing the laminations together. The yoke while necessarily a part of the equipment required for producing the 16 pictures thus becomes an integral part of this enlarged tube.

Lens Aberration and Usable Cathode Area

The maximum useful area of the photocathode is a 1-1/8 inch diameter circular area for the 2 inch cathode-focus electrode tubes and a 1-3/8 inch diameter circular area for the 3-5/8 inch cathode-focus electrode glass end. Part of the limit on the useful cathode area is electron optical for not all of the diameter of the lenses formed by the 1.732 inch i.d. cylinders in the 2 inch tube or by the 2.100 inch i.d. cylinders in the 3-5/16 inch tube can be used without the defects inherent in the thick E. S. lenses becoming excessive. Thus, pincushion distortion, curvature of the focus field, coma, spherical distortion, and other lens aberrations become more and more apparent as more of the outer parts of the lenses are used, just as in the case with thick lenses in glass optics (where, however, more variables are available for correcting the defects of the spherical lenses). The useful cathode area is somewhat less than the maximum in several tubes because of insufficient image-object reduction ratio - - 16 "full-size" images on the fluorescent screen will either overlap or several would be off the edge of the fluorescent screen. Somes tubes did not have adequate flatness of field near the flat cathode to permit use of such a large cathode diameter -- the curvature of the focused image "plane" is excessive except for about a third of the stated maximum diameter, but this was caused by too long an electrode cylinder immediately adjacent to the grid mesh and has been corrected. (See Section III).

Charges by Stray Electrons

The photoelectrons from the outer parts of the cathode are also more susceptible to the diverging field lines near the edge of the higher potential element of each lens and may strike the electrodes causing the emission of secondary electrons which will not be focused on the screen but will reduce the contrast in the picture due to the increase in background light. These electrons, and marginal electrons as well, may get in a force field which impells them through the spacings between the focus electrodes to strike the glass walls. The glass will then acquire a charge which may enhance this effect but which in any event will distort the normal electrostatic lens field near the charged area. Usually this charging can be eliminated by conductive coatings on the outside of the glass in the form of rings tied to the appropriate focus electrode potential -- the lower potential coating extends beyond the space between the electrodes so as to "direct" the stray electrons back toward the higher potential electrode. It is expected, from previous experience, that if only a few electrons strike the glass in a short period of time the leakage through

the glass is sufficient to prohibit the build-up of charge on the glass. The glass area beyond the anode aperture, as seen from the cathode side, must, however, have an internal conductive coating inasmuch as the number of secondaries or reflected primaries formed at the aperture and other electrodes which strike this glass area, at the glass-sealing area under the deflection yoke, have established charges which could not be completely discharged through the glass, to a conductive coating, grounded or at anode potential.

Field emission from the edges of the electrode cylinders has not generally been a problem. The methods of treating the electrodes prior to final assembly as well as the method of keeping the electrodes always hotter than the cathode during the cesiation steps play an important part in this favorable result. However, discharges, flashes, or field emission can occur if the electrode voltages are improperly adjusted. The most likely cause of these discharges is the excessive electron bombardment of the electrodes, electrode edges or the glass near the electrode edges. Field emission between the post-acceleration rings was somewhat troublesome but the proper overlap of the aquadag edges by the chrome oxide, proper spacing between the conductive aquadag rings (1-1/8 inches needed for the smaller, single post-acceleration voltage tube), and the use of an external conductive coating at anode potential over the insulated chrome oxide layer apparently successfully prevents the accumulation of charge (external as well as internal).

Spurious Photo-Emission

Photoemission occurs from the electrodes between the antimony evaporator and the photocathode surface. This electron emission is not focused at the same voltages as the photocathode and so contributes general illumination to the image area, thus reducing the available contrast. However, a mask on the photocathode restricting the illumination to the usable area makes the actual emission tolerably low. Also, a black coating on these electrodes as well as on the anode aperture disc decreases the amount of light reflected in the tube and lowers the emission of the electrodes. Photo-emission from the grid mesh bars is extremely low, factor of 500 less, compared to that from the photocathode. However, there is sufficient emission from the edges of the bars that several milliseconds exposure to a steady source of light will cause the same integrated light flux from the fluorescent image with the grid mesh negative to the cathode so as to stop the emission from the cathode, as can be obtained from the same light source with the photoelectrons from the cathode pulsed-on for only one microsecond. Inasmuch as it is desirable that the equipment be capable of operating with a steady source of light (i.e. unpulsed) a means was needed for keeping the photoelectrons from the mesh from striking the screen until a short time before the sequence of pictures is to be started. A synchronously operated iris diaphragm shutter to block the light from reaching the grid mesh and photocathode until several microseconds before the sequence was considered to be unfeasible with presently known camera shutters, so methods of gating the tube were investigated. The simplest workable gating (or blanking) of the emission from the grid mesh was to deflect the electrons away from the anode aperture opening to impinge on the aperture disc. This deflection has been accomplished as will be discussed in detail in the circuit sections of the report.

Discussion of Possible Improvements in the Multiple-Frame High Speed Shutter Tube

The resolution of the shutter tube can be improved by shortening the first accelerating cylinder to about 1/4 the diameter of the cylinders. Then two accelerating cylinders about 1/3 the diameter in length should follow this first one. Succeeding cylinders will be about one diameter long as presently used. Considerable reduction in the already small amount of pincushion distortion can be effected by a decrease in the distance between the main lens and the fluorescent screen. This decrease can be accomplished only by a concurrent shortening of the deflection yoke. The voltage ratios for optimum focus should be more favorable since the condition of minimum pincushion distortion and optimum focus have been observed to occur at the same operating potential. If curvature of the field of focus persists after having made these changes, the resolution can be further improved by using either a curved cathode or a curved screen, either one concave toward the main lens. (Screen curvature will be of less benefit but it could then be made a part of a Schmidt camera). The mesh, if still used, will have to have the same curvature as the cathode.

The overall tube gain can be increased by enlarging the usable cathode area. However, the fluorescent screen image should still be about 10 mm on a side until means of obtaining resolutions better than 30 line pairs per mm can be secured from the phosphor, without excessive loss in light output. Gains of a factor of 4 could be realized without too much difficulty by this increase in cathode area. A factor of 10 might be realized in the overall photographic gain through the use of specially designed light optical camera equipment, as mentioned in section K of this report. If the factor of 40 times the presently available gain, approximately 33 were attained, then the shutter tube camera would record a 5 foot-candle level of illumination during a one microsecond exposure. A 200 foot-candle level is presently attainable. Calculations of the minimum level of illumination attainable with the image orthicon for a one microsecond exposure time will show that quanta limitations require that a few foot-candles of illumination fall on the photocathode. The image orthicon is the most sensitive imaging tube available today. The image isocon, a more sensitive imaging tube, is still in development.

A brief discussion of other methods of attaining high speed photography at low levels of illumination is in Appendix I.

Appendix A

The light gain figure (page 14) was obtained by measuring light flux densities at the input and output with an exposure photometer made by Salford Electrical Instruments Ltd., London. The resulting light gain figure will then be a function of the spectral characteristics of the light source. One can eliminate this dependence by using a blue-sensitive $SbCs_3$ semi-transparent phototube (s-9 spectral response curve) to measure both the input light flux incident on the S-9 shutter tube's cathode and the output light flux from the fluorescent screen. The choice of an S-9 phototube for these measurements is a happy one inasmuch as not only is its response, in microamperes of current, to the light emitted from either the blue-emitting screen or the green-emitting screen directly related to the opacity obtained on the Tri-X panchromatic film but also it has the same spectral response as the photocathode in the shutter tube. Therefore, the light flux gain figure measured with such a photocell and multiplied by the image-to-object ratio of the

shutter tube might be called its photographic light flux density gain (G_m). The color temperature of the tungsten source of light is often not quoted as the position of the S-9 (and Tri-X film) response curve is favorable for its omission over a narrow range of temperatures centering about 2870°K. The photographic light gain was measured by this method, for example, on tube No. 62854 yielding the figure of 20 at an image-to-object ratio of 1:2.

To determine the gain at any desired wavelength interval within the response of the S-9 photosurface the following formula may be used: -

$$G = G_m \frac{S \quad J}{S \quad J \quad d}$$

where

- G is the gain in the wavelength interval
- G_m is the measured flux density gain of the tube
- J is the response at of the S-9 surface
- $_1$, $_2$ are the limits of response of S-9
- S is the light flux from the tungsten source of color temperature 2870°K, say, (relative units only need be used) at

Appendix B

The cascaded phosphor screen, photosurface method requires an extremely short decay phosphor which is less efficient than the sulphide type. The time between pictures may be governed by this decay time instead of by the speed of the sweep circuits as is the case at present. The decay time must be shorter than one microsecond so that the buildup of the background does not become appreciable before the end of 32 microseconds, i.e., 16 pictures spaced 2 usec (N2). The ultra-violet component of the emission from ZnO Zn has a short enough decay time but its use introduces the problem of reducing the visible emission. The requirements of short decay time are more stringent than in the flying spot scanner inasmuch as successive pictures are superimposed, thus permitting a buildup of the background. Some loss of detail will be experienced because of the finite distance between phosphor and photosurface although this distance can be made neglibible if a supporting mesh is used, in which case the mesh will establish the limiting resolution. The difficulties of processing all the photocathodes to a uniformly high sensitivity while ensuring that excess cesium does not remain in the tube are great.

Secondary electron multiplier stages using MgO Mg surfaces are preferred to the phosphor screen-photocathode stages on the basis of processing schedules and decay-time considerations. However, the requirements of good resolution and high gain per stage are conflicting. Thus, a 1000 mesh screen is obtainable for use in a Weiss type multiplier but the gain per stage is less than 2.5 because of poor primary electron collection on this screen and inferior secondary electron collection by the second stage. The resolution deteriorates, of course, when more stages are added. A vane type (or venetian-blind type) of multiplying stage might have a gain

of 5 but its construction would greatly limit the resolution. (There is a slight possibility that 200 line meshes, say, could be stacked to form a structure similar to a venetian-blind multiplying stage although proper collection of the secondaries may not be possible). Vanes, or inclined holes, or conical holes can be formed in photosensitive glass but resolutions of 25 to 50 vanes per inch are about the best which can be expected. Of course, large area stages can be made which will transmit considerable intelligence, so this approach to securing additional gain in the shutter tube should be pursued at least to the extent of further study coupled with the performance of preliminary experiments.

Storage of the picture information on an insulator target may be advantageous when the stored charge can be read numerous times before erasure. Standard means of amplifying (secondary electron multipliers and tube amplifiers) the signal reading the stored charge will minimize the charge which had to be stored on the insulator target in the first place and will also permit some control of the contrast in the final picture.

The image orthicon (R1) will just detect an illumination level of 10^{-4} foot-candles at its photocathode if the signal charges are added (stored) for 1/20 second. Therefore, to just detect a subject in one microsecond, the illumination level must be 3.33 foot-candles at the photocathode. This calculation neglects the gain factor of 7 resulting from the eye's storage of 0.2 second duration, so the illumination level would probably have to be closer to the 23 foot-candles at the photocathode of the standard image orthicon to be clearly visible. Possibly a higher level would be required for photographic purposes. By cooling the standard image orthicon target so that the signal charge is not read off in one scan, the 3.3 foot-candle level would again be adequate. This illumination level is the minimum level which can be attained with present day storage tubes used for one microsecond exposures (W 3).

Several papers (R 2) have indicated that about 25 electrons must be emitted by incident light quanta before an elemental area is clearly recognizable as a signal area. (on the basis of the fluctuation noise arising from the random process of absorbing a light quantum with the emission of a photoelectron this figure represents a signal-to-noise ratio of 5 to 1). It was also shown (R3) that about 25 electrons are emitted from an elemental area of the image orthicon's photocathode during the 1/30 second storage time under the minimum usable light level of 10^{-4} foot-candles at the photocathode. Therefore, the minimum attainable light level can be decreased only by an increase in the quantum efficiency of the photocathode, by an increase in the elemental area of the photocathode, or by longer storage times. (The eye and brain apparently can make all these adjustments to reduce the minimum light level that it can see to about 10^{-7} foot-lamberts scene illumination).

The assumption that the minimum or threshold signal-to-noise ratio as set by fluctuation noise must exceed 5 may not be correct for applications in which the photoelectrons emitted during any specified time (one microsecond to return to our shutter tube problem) are stored after multiplication in such a manner that the stored charge may be read several times before erasure of the charge. Signal-to-noise ratios of 2-to-1 may possibly be tolerated with a subsequent decrease in minimum light level of a factor of 6 (i.e., 4 photoelectrons emitted during the 1 usec open shutter interval may be detected as a signal).

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NOTES

1. The term "line pairs per millimeter" refers to the number of equally wide white lines which can just be resolved -- the black lines not being counted separately. The optical engineer means the same thing when he uses the term "lines per millimeter". The television engineer, however, counts the black as well as the white lines and his lines per picture would be twice the number obtained on the optical or "line pair" basis.

2. Of course this cascade amplification can be applied after the 16 pictures are focussed on the first screen. However, the resolution requirements on the cascade screen-photocathodes become of greater importance unless the cascade arrangement has 16 times the area it would have in the arrangement above --but then it will be extremely difficult to construct and process.

3. The Metrechon target when used in its most sensitive mode requires a writing current of 0.6 microamperes in order to establish on one elemental area in one microsecond a charge which may be read for several minutes.

   (ref. R.C.A. Review, Vol. XV, No.2, June 1954, p. 145 -- but also refer to talks of W. O. Reed and Dr. C. S. Szegho (Rauland) and J. N. Dyer, J. W. Hollywood (of Airborne Instr. Lab.) which were presented at June 20, 1949 I. R. E. Tube Conference on Electron Tubes in which the fundamental design and results of tests of the coplanar storage target tube were described. The tube work was performed at Rauland under subcontract to Airborne Instruments Lab. who had the prime contract No. W-28-099-ac-307 with Watson Labs.)

   $i \text{ (amps)} = 1.59 \times 10^{-19} N \qquad N = \text{nbr. of electrons/amp sec.}$

   $N = \frac{6 \times 10^{-7}}{1.59 \times 10^{-19}} = 3.77 \times 10^{12}$ electrons/sec. at 0.6 uamp charging current

   or $N_1 = 3.77 \times 10^{6}$ electrons required for charging an elemental area

   Therefore, the lower capacity and lower working voltage of the target insulator in the image orthicon enables it to detect a charge which is 10^5 times smaller than can be detected with the metrechon storage target.

   Similar numbers of electrons (10^6 to 10^7) are required for charging the insulators deposited on metallic meshes to establish an identifiable signal element.

To use the image orthicon target as a means of storing the 16 pictures a reduction in the present 500 line definition capabilities to a 120 line definition, television lines, must be accepted unless the target is completely modified to occupy a larger area, and unless a finer mesh, 1000 lines per inch, is used instead of the 500 line mesh which is now used.

Tables 1 and 2 list the advantages, disadvantages, equivalent noise input and means of improving the available photoemissive and photoconductive devices.

SECTION III

ELECTROSTATIC FOCUS ELECTRODES

Electrostatic focusing of the photoelectrons from the cathode onto the fluorescent screen was selected in preference to electromagnetic focusing because of the greater ease with which a reduction in image size can be obtained. Furtermore, E.S. focusing does not rotate the image nor cause the S-bend distortion that E.M. Focusing does. For instance, the M.E. 1201 (loc. cit) which has a fluorescent image 3 to 4 times as large as the light "image" at the photocathode, can only, with difficulty, be made to give a slightly reduced size image and it is somewhat doubtful that the reduced image could be deflected to 16 different positions without considerable distortion or rotation.

The first E.S. design had to accept the limitations imposed by the largest standard yoke size available which was 2-3/16" inside diameter and 3 inches long. Therefore, the maximum O.D. of tubing which could be used for the photocathode and focusing electrode was 2 inches inasmuch as 3/16 inch had to be allowed for the cesium side tube and exhaust tip-offs. To make full use of the inside diameter, the electrodes were painted strips of liquid bright platinum and the glass in between the strips was coated with Cr_2O_3. A usable tube did not result because of the near impossibility of processing the $SbCs_3$ photosurface without at the same time causing cesium leakage across the gaps between the electrodes. Also, marginal electrons striking the insulator areas set up E.S. fields which distorted the image into weird shapes. However, these first tubes helped to determine the overall dimensions of future tubes, and figures were arrived at as to the deflection angle and power which later tubes would require.

The second design eliminated electrodes painted on the glass, except at the anode and beyond the main focusing electrodes, and sought to produce a 1:1 image-to-object ratio, linear dimensions. This tube design used the electrode mounting which has since been used in all of the 2 inch diameter glass tubing (Section IV). The overall tube length was 21 inches; the fluorescent screen was 5-3/4 inch usable diameter to accommodate sixteen 1 inch x 1 inch pictures.

Three main faults were eliminated by experimentation:

(1) The neck area under the deflection yoke was bare for about 1 inch due to the temperatures required for sealing the cathode and electrode glass end to the fluorescent screen end. Electrons reflected or scattered by the anode aperture struck the glass, charging it too much for an external conductive coating to completely discharge the area. Barium getters (Kemet type 61018F) which were

PHOTOEMISSIVE DEVICES FOR LOW LE

DEVICE	ADVANTAGES	DISADVANTAGE	EQUI'
1. Image Orthicon	S-4 photosurface Employs storage integration gain	Noisy due to shot and Johnson noise of "black level" beam. Slow response (1/30 sec or longer). Incomplete storage target discharge	10^{-4} to D
2. Image Dissector	Excellent half-tone rendition	No storage	Rough photo
3. Iconoscope		High level illumination required because of amplifier limitations and redistributed secondaries of mosaic.	? 0.
4. Image Converter	Slight storage in screen Direct view Amplification of 10 at about unit image/object ratio	No scan so cannot view remotely May be noisy due to high fields, gas, etc.	10^{-3} temp. surf
5. Photomultiplier	Very high signal/noise ratio Fast response	Not an imaging device No Storage	10^{-10} (10^{-9}
6. Photocell	Best signal/noise ratio Fast response	Not an imaging device No storage	10^{-11} (10^{-9}

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SSIVE DEVICES FOR LOW LEVEL ILLUMINATION

	EQUIV. NOISE INPUT*	MEANS OF IMPROVING
on noise response mplete	10^{-4} foot-lamberts according to Dr.Clemens	Image converter amplification) suggested by Clemens Improved storage target) and Johnstone Different mode of operation
	Roughly 1.0 foot-lamberts S-1 photosurface	Use S-4 photosurface - cool if necessary Sacrifice definition to attain higher output into S.E. multiplier. Not too much advantage, Store picture on graphecon or similar signal storage tube (graphecon is probably much less noisy than image orthicon - but usually requires more than one reading scan to discharge target)
iired tions es of	? 0.1 foot-lambert S-1 mosaic	Possibility of adding multiplier behind storage surface - then tube becomes similar to Hergenrother tube. Improve mosaic storage target.
ely lds,	10^{-3} foot-lambert for S-1 at room temp. probably less than S-4 photosurface	Cool tube, especially photosurface. Higher voltages. Proper choice of photosurface and fluorescent screen material. Cascaded amplifier sections - enclose in Dewar-type flask. - Storage section also possible.
	10^{-10} to 10^{-13} lumen (10^{-9} to 10^{-12} foot-lambert, approx.)	More stages. Higher leakage resistance. Cool tube (especially photosurface). Use high speed shutter tube in manner similar to image dissector. Noise level is that of H.S. tube. Sacrifice light gain in H.S. tube by operating at reduced voltages, thereby minimizing noise.
	10^{-11} lumen for S-4 photosurface (10^{-9} foot-lambert, approx.)	as for photomultiplier

* minimum usable signal level will usually be somewhat larger than this value.

2

PHOTOCONDUCTIVE DEVICES

DEVICE	ADVANTAGES	DISADVANTAGES	NOISE CHARACTERISTICS	MEANS OF IMPROVING
1. Vidicon Type	High quantum yield Slight storage	Sluggish discharge Noisy (both current and photon)	Signal/noise ratio 100 at highlight levels max sens 300 ua/l	Improved amplifiers (such as inclusion of S.E. multiplier Image Converter amplifier in front of vidicon should give gain of 5 to 10 times in signal with no significant increase in noise (New reading means (New target construction (See report on storage target Increase electron density in scanning beam and increase target area.
2. Mirror Tube (Schaffernicht)	Direct view tube	Not a scanning tube	Possibly comparable to the vidicon	Complete data lacking Developed for infrared work.
3. Lead Sulfide Cells		No image Wrong spectral response for present application	About the same as an S-1 photocell at same temperature	
4. Phototransistor and CdS crystals	High quantum efficiency ((10^3 to 10^5 us/lumen	No image Exact focusing of light spot required. (.01 cm^2 sens.area) About 2 mc upper freq limit in present state of the art	noise proportional to 1/frequency so should not be noisy in video applications	More data required.

flashed across the area removed the charging difficulty but adversely affected the sensitivity of the photocathode. Silver evaporated across the gap satisfactorily but it was felt that the conductivity was too high and there was a possibility that it might oxidize becoming photosensitive or that it might globulate during the processing of the $SbCs_3$ photocathode. Finally, aluminum was evaporated across the gap (at the end of the degassing bake-out exhaust and prior to the formation of the $SbCs_3$) with complete success.

(2) Static charges were built up on the Cr_2O_3 rings separating the post-acceleration anode rings partly by corona along the outside of the bulb and partly by secondaries, or reflected primaries, from the inside. The distortion of the image on the screen became greater as the image was deflected from the center. An external conductive coating electrically connected to one of the post-accelerating rings eliminated this trouble.

(3) The resolution of the first few pictures was quite poor even after the main faults mentioned above were eliminated. A magnetic shield of soft iron placed over the focusing electrode end of the tube vastly improved the resolution capabilities of the tube and finally it was found necessary to magnetically shield the high voltage end of the tube to attain maximum resolution. Inasmuch as most of the disturbing magnetic fields were radiated from the 60 cycle transformers it is possible that the resolution of single one microsecond pictures would have been unimpaired by these fields. However, adjustment of the focusing voltages must be made under repetitive pulse conditions so it is desirable to have optimum resolution at all times. Permanent (D.C.) magnetic fields exist on the relay rack which were not properly shielded by the soft iron, so eventually the magnetic shield was made of a .060 inch thick cylinder of mu-metal since it was found that extremely low magnetic fields (D.C. or otherwise) in the focusing region caused astigmatism in the fluorescent image.

A flat photocathode was considered to be a desirable feature of the shutter tube both because standard optical lenses are corrected for flat-field imagery and because it seemed necessary at the time to use a flat, thin mesh close to the photocathode in order to have a high enough accelerating field at the cathode with less than 100 volt amplitude pulses. The use of cylindrical "immersion" lenses to focus the electrons from the photocathode on the fluorescent screen is known to produce serious curvature at the screen of the focused field of a flat photocathode. Ordinarily, this is corrected in the image tube by making the cathode concave towards the field, so that its center of curvature is approximately at the center of the lens(R 1). But even with this correction which ensures good focus on a flat fluorescent screen the pincushion distortion of the image can be quite large (caused by increased magnification of the image for object points further away from the axis). Therefore, a different type of electrostatic lens was sought. The symmetrical type of lens appeared to offer possibilities inasmuch as the ratio of the convergence to the divergence properties of the lens can be varied almost at will simply by changing the potentials on either side of the center electrode relative to one another. Also, the focal length of the symmetrical "saddle-field" can be varied over a large range for fixed dimensions of the electrodes and electrode spacings (R 2).

Furthermore, the possibility of producing a flat or even slightly diverging field near the cathode with an approximation to the "saddle" lens was intriguing. Therefore, a number of electrode configurations were drawn on resistance paper and the equipotential lines plotted using the G.E. Analog Field Plotter until finally the shape and distribution of the equipotential lines looked promising and tubes were constructed with these electrode configurations. Slightly diverging fields could be attained close to the cathode (Figures 18 and 19) but when the electrode potentials were adjusted to give the diverging fields, rather weird patterns developed on the screen. Apparently the electrodes and the gaps between them, with consequent charging of the glass near the gaps, received quite a spray of photoelectrons which caused the emission of secondaries as well as scattered primaries. Larger diameter electrodes were indicated, or more gently curving divergence lines. The attempt to use diverging lines near the cathode was abandoned in favor of the use of equipotentials parallel to the cathode and grid mesh with the object of providing a relatively high acceleration to the electrons in a direction parallel to the axis, thus obtaining a larger percentage of paraxial electrons, or near paraxial, and thus reducing the aberrations to which tangential and sagittal electrons are subject. Figures 20 and 21 which are complete equipotential plots of the final tubes show how the potential surfaces flatten near the mesh. Furthermore, this provision of initial acceleration parallel to the axis has the same effect electrically as the physical lengthening of the distance between the object and the lens system so the overall tube length will be shorter for a fixed image size. Also, the lenses are made weaker, that is, they have less bending power on the faster electrons. One slight disadvantage of this mode of operation when a mesh is used for the shutter tube grid, is that the mesh is sometimes almost in focus and moire beats between the mesh and lines of separation comparable to that of the mesh (or of the mesh bar width) become noticeable and interfere with the resolution of the picture. Two hundred line mesh with .0007 inch wide bars was commonly used. However, 120 line mesh with .0006 inch to .001 inch wide bars has been also used.

Relatively weak lenses start converging the electrons after this initial axial acceleration. Then the saddle-field lens is employed for providing the main focusing action on the beam. By a proper choice of the divergent and convergent properties of the saddle lens, it appears to be possible to almost completely eliminate the pincushion distortion introduced by the preceding "spherical" lenses. When the pincushion distortion is small, the image also generally has better flatness of field, and resolution at the screen of 12 to 20 line pairs per millimeter are obtained. However, when the image is required to be at a fixed demagnification of the object, say at one-half the size, the problem of satisfying all of these conditions becomes more difficult if the overall length of the tube is to be kept within reasonable limits of 17 inches, and the adjustment of the electrode potentials becomes more critical. In fact, since the saddle-field lens is the main lens in the high speed shutter tube, the biggest improvement in image quality at reduced image sizes will be achieved by shortening the distance from this main lens to the fluorescent screen. And this distance can be shortened only by shortening the 3 inch yoke and by reducing the effect of its stray field by magnetic shielding of the electrostatic lens and anode aperture. It is readily observed that by reducing the voltage on the central electrode of the main lens, thus making it a stronger lens, below that required for best focus that the "image" can actually be made to have a barrel-type distortion.

The limiting aperture in most of the tubes is the photocathode. Tubes in which the anode aperture did the limiting had only slightly improved resolution. Possibly a slight shift in the position of the anode aperture with the aperture just starting to limit would further increase the resolution a 1/4 inch long, 3/8 inch diameter aperture will just cut-off the outer (approximately 1/16 inch) circumference of the photocathode as seen in its image on the fluorescent screen. Limiting apertures placed ahead of the main lens, i.e., on the object or photocathode side, are often used in glass optics to reduce lens aberrations and lens distortions. However, apertures in electron optics generally tend to make stronger lenses and the curvature of the equipotentials near the edges of the apertures becomes rather large. Therefore, no limiting apertures were used in front of the main lens. The anode aperture which is used in the most recent tubes is a 5/8 inch length of 23/32 inch I.D. tubing, the 5/8 inch length being found desirable from the point of minimizing "cross-over" focusing of the photocathode at the fluorescent screen.

"Cross-over" focusing is the intense bright spot, or sometimes a general haze, which occurs at certain voltages on the electrodes. It usually appears when the voltage on the two electrodes closest to the cathode exceeds a few hundred volts. The spot is often in sharpest focus at the same voltages which focus the photocathode picture on the screen. The spot has been most prevalent in tubes whose electrodes are coated with carbon. Slight changes of the relative voltages on the electrodes will often eliminate the spot without harming the focus of the desired picture. The electrons producing the spot at the screen definitely come from the general photocathode area, moving a restricted area of illumination over any part of the cathode area produces "the spot". The spot can be cut-off by the use of a negative mesh grid voltage. From its behavior it is believed that the spot arises from marginal electrons hitting the electrodes near the mesh causing the emission of secondary electrons which are focused onto the screen. However, a circle spot has not been seen. The explanation of Dr. H. Bruining that the bright spot is due to the emission of secondaries liberated by the focused bombardment by positive ions of the photocathode cannot be overlooked but as yet no deteriorated area of photoemission has been observed in the center of the cathode (other than the bad areas found when the mesh actually touched the cathode). Of course, the explanation can be that by coincidence the photocathode is both focused and brought to a crossover point at the same time. A saddle-type lens can form several focused pictures and several cross-overs merely by slight changes in the voltage ratio of the three electrodes. A typical set of electrode voltages for best operation of the tube is given in Table 3.

REFERENCES

1. Jacob, L., "An Introduction to Electron Optics", Methuen Monograph, Page 71 - quoting Ramberg and Morton, J. A. P. 7, 451 (1936).

2. Cosslett, V. D., "Electron Optics" Oxford Press, p. 63 (1946) also R. V. Jordan, et al, "The Sylvania Technologist", Vol. VI, No. r, Page 92, (Oct 1953).

SECTION IV

TUBE CONSTRUCTION

Throughout most of the contract period the photocathode and focusing electrode section of the tube was restricted to an outside diameter of the glass envelope of 2 inches to be able to slide the largest available standard yoke over this section to its proper position on the tube. Attempts to make use of the full inner diameter of the glass by painting the elctrodes on the glass (Hanovia liquid bright platinum No. 5) failed not only because of leakage across the insulator gaps caused by antimony and, primarily, cesium deposits but also because of non-uniform charging of some of the gaps by marginal electrons or by photoelectrons from the platinum electrodes. It would appear from tests made early during the contract period that only the low voltage electrode closest to the photocathode could be deposited on the glass.

To make use of the largest diameter electrodes possible, the glass tubing was used as a component part of the structural assembly. Small Kovar metal buttons intended by the supplier for electrical connections were ground to the length of .115 inch required by our use and sealed into the 7052 glass tubing at predetermined positions. A cylindrical mandril of minox, (an iron specially cast for uniform heat properties) was made to adjust the depth to which the buttons were pushed during sealing. However, variations in glass diameter and thickness as well as lack of good control of the mandril as it "whipped" around in the lathe (frequent indicating of the axial rotation of the mandril was required) reduced the precision with which the Kovar buttons could be sealed to the proper distance from the axis of the cylinder. It was found that the Kovar buttons always pulled away from the mandril by a variable amount. This situation improved when precision glass tubing (1.900 inch I.D. and 2.020 inches O.D.) was used in that the Kovar buttons always pulled away from the mandril by approximately the same .006" $\pm$ .001. However, the mandril still caused errors to appear owing to its running off axis during the long sealing procedure. Therefore, the mandril was not used when the precision glass tubing was available.

Following are the steps in fabricating the glass assembly, Figure C-1.

Step	Procedure
1. Cleaning	a) Wash glass parts with Softasilk Liquid Soap.
	b) Rinse well with de-ionized water.
	c) Dry in forced hot air.
	d) Kovar buttons are supplied H_2-fired and if carefully handled no further cleaning.
2. Button Sealing	a) Kovar button positions are marked on glass tubing with diamond scratching pencil.
	b) On the glass lathe the tubing is preheated, holes blown successively in appropriate positions and Kovar buttons sealed in appropriate holes (one hole at a time, of course).

3. Side Tubulations

The cesium and exhaust sidetubes are sealed to the main cylinder at appropriate times when the glass is being worked in that area while making the Kovar button seals.

4. Cathode Faceplate

a) Sealed to flared end of 7052 glass cylinder after the electrode buttons have been sealed.

b) Two buttons at 180° are sealed as close to face as possible for contact to photocathode.

c) The face end of tube is partially annealed in a carbonizing flame.

5. Platinum Contacts

a) Hanovia Liquid Platinum Bright No. 02, an organic compound of platinum (traces of iron for improved wetting of the glass) is painted from each of the two Kovar contacts onto the cathode face to form two 120° rings 1/8 inch wide and 1-1/4 inches inside diameter.

b) A band is also painted to within 1/4 inch of the open end of the glass cylinder and contact leads made to the closest Kovar buttons, which mount the anode cylinder and anode aperture.

6. Oven Bake

a) A gentle stream of air is circulated in the assembly while the oven temperature is rising to $550^{\circ}C$ in order to completely oxidize and expel the organic vapors from the Platinum Bright. The air flow must be stopped at this point or the faceplate will not reach proper annealing temperature.

b) The oven temperature is raised to $580^{\circ}C$ and held for 15 minutes to ensure thorough annealing of the glass and Kovar seals.

c) The oven cools slowly enough without additional power to avoid setting up strains or cracking of the glass.

d) When temperature is below $150^{\circ}C$, the glass assembly may be removed.

7. Platinum Contact

a) The platinum film does not always make good contact to the Kovar button so a little daub of Sauereisen Conductalute is applied at each junction.

b) A thin layer of Cr_2O_3 (Section III) is applied over the appropriate edges of the platinum to inhibit cesium leakage and surface discharge along the glass.

c) The bulb is baked at $260^{\circ}C$ for 20 minutes to drive off most of the water of crystallization in the silicate binder of these cements.

8. Conductive Photocathode Base

a) It is at this stage that the aluminum oxide and the palladium are evaporated onto the cathode area between the two platinum contacts of step 6.

b) If the conductive base is the iridized film, that is deposited prior to step 1.

Prior to mounting the type 304 S.S. focus electrodes in the glass assembly, a few sub-assemblies must be prepared.

The Mesh Assembly

120 line or 200 line nickel mesh (N 1) is stretched over a ring (Drawing 21212) and a clamping ring (Drawing 21213) positioned over it with the rivet holes in alignment. Aluminum rivets clamp the assembly. Attempts to keep the mesh under tension during the riveting operation were not completely successful so a tightening ring was added (Figure 21) which used flexible tantalum springs for mounting and keeping the mesh under light tension. This solution was not always successful owing to the weakness of the mesh and the differential expansions of the 304 S.S. mounting and the nickel mesh.

The assembly is soaked in acetone and ether; a nickel etch solution was decided to be superfluous after comparative tests. Glass-bead-insulated mounting wires are welded to 2 of the mesh assemblies and the mesh mounted in its cylinder (the one adjacent to the cathode face). The third mounting tab of this cylinder is removed and insulated by glass beads before remounting and connected to the mesh for the grid connection.

Evaporator Assembly

The evaporator shield (Drawing 21210) is spot-welded at the high voltage end of a cylindrical electrode (Drawing 21215) which was usually the third electrode from the photocathode.

The 99.9 percent pure antimony is melted under an atmosphere of argon to wet a circular channel of Comet metal at selected points (N 2). The evaporator channel is self-supporting from its ends near the bottom of, but clearing the sides of, the shield (Figure 23).

A small chip of electrolytic manganese is held against the center of a 1-1/4 inch tantalum wire (.015 inch diameter) by a wrapping of .006 inch molybdenum wire. A short nickel tab is welded to each end of the tantalum wire, and this assembly is mounted in the shield above the antimony channel so that the hottest part and largest section (the Mn) is over the center of the antimony channel which has purposely not had any antimony melted onto it (thus, the antimony evaporation occurs from two line sources which are approximately 150° apart).

Anode Aperture Assembly

The first anode electrode consists of a short cylinder (Drawing 21215) in which is mounted the anode aperture assembly, the short platinum ring on the glass as mentioned above, a coating of aquadag (Section IV) extending the length of the

fluorescent screen end of the bulb which lies under the deflection yoke and a connecting film of aluminum evaporated on the pump over the sealing area between the platinum ring and the aquadag.

The anode aperture assembly consists of an electrode cylinder (21215), an aperture retaining ring (21209), and a 5/8 inch length of .720 inch I.D. tubing (type 304 as are all the other electrode parts). The aluminum evaporators are mounted to the aperture assembly as shown in Figure 23.

Aluminum Evaporator

The aluminum evaporator is best described by reference to Figure 23. The stainless steel shield prevents the evaporated aluminum from reaching the lower voltage electrodes or the fluorescent screen.

Electrode Mounting in the Glass Assembly

The electrodes are mounted in the glass cylinder by spotwelding the tabs on the cylinders to the appropriate Kovar buttons. The mounting is rugged but is probably quite microphonic, although tests were not devised to check the effect of mechanical vibrations on the resolution of the image (Figure 24). Careful alignment of each electrode cylinder by rotating the glass assembly with the electrode held in place by spring tension on the tabs was judged to be adequately precise when performed by a careful, patient worker.

The final operation requires careful axial alignment of the cathode-focus electrode assembly with the fluorescent screen end of the tube (Section IV) in the glass lathe. A mild flame is directed at the screen end of the bulb, it having been found with similar type operations at Rauland that the moisture which would otherwise collect in large amounts on a cool screen will burst or peel the aluminum film during subsequent stages (evacuation) of processing the tube. Argon is introduced through the cesium tubulation up to the moment of sealing the two ends to help minimize the collection of moisture on the electrodes. After the seal is made and the glass is cool enough at the cesium inlet, a forepump is connected to the cesium tubulation and the tube is exhausted to remove the excess moisture which could not be entirely eliminated by the preceding steps. It is important that the antimony, palladium, and manganese be exposed to as little moisture for as short a time as possible.

The cesium container and pills (a 1:1 mixture of cesium chromate and silicon powders in a nickel cup assembly) is sealed at the proper tubulation and the tube is ready for sealing onto the processing pump. (Figures 25 and 26).

The parts from which the tubes with the larger electrodes (2.100 inch I.D.) are made are described in Figures EX 21257, 21258, 21259, 21268, 21270, 21282. These are assembled on the precisely machined mandril. The mandril is mounted on a heavy floor-type drill press. A .20 inch diameter pyrex glass rod is placed in the groove of the preheated gunite (N3) and brought to its softening point with a gas and oxygen flame. The oxygen supply is cut-off as the assembly is quickly lowered to press the mounting tabs (Drawing 21271) into the pyrex rod. After the glass is colled below its flow point for a couple of seconds, the jig is raised and the next glass rod placed in the groove. Three glass rods suffice for rigid, precise holding of the

NOTES

1. These meshes are obtained from Buckbee-Mears, St. Paul, Minn. and are of the order of .0003" thick and have more than 80% relative light transmission.

2. Comet metal is a nichrome alloy containing a small amount of iron which is easily wetted by antimony. This material was suggested for this application by G. P. S. Freeman of Cinema-Television Ltd., London, England.

3. Gunite is a high test cast iron with less than 3% C and 2% Si made by the Gunite Corporation, Rockford, Illinois.

electrodes. Air is blown through the hole in the mandril to hasten its cooling for removal of the electrode assembly from it. Fig 28 shows parts used in Shutter Tube.

SECTION V

THE FLUORESCENT SCREEN

GENERAL DISCUSSION

The fluorescent screen which is used in the final tubes constructed for this project is the result of a series of investigations of the luminous efficiency, resolution capabilities, and decay characteristics of available fluorescent powders. ZnCdS.Ag fluorescent powders have been selected for the Shutter Tube because of their high emission efficiency under electron bombardment. Two types of the phosphors available from DuPont had a sufficiently small particle size to give a fine-grain fluorescent screen with resolution capabilities of 20 to 30 line pairs per millimeter. They are nickel-quenched to reduce the decay time to a little less than that of the standard R.M.A. P-11. The relative spectral response of the "blue" #1411 and the "green-yellow" Q3-2657 phosphors is shown in the curves Figure 28.

The green-yellow emission of the Q3-2657 is preferred to the blue emission of the 1411 because the eye has 5 times the response to the green than to the blue light emitted by these phosphors, as directly measured by a photronic cell having the spectral response of a photopically adapted eye (Nl). As is well known (,) the eye rapidly gains in its acuity as the brightness of the test object increases. Therefore, this factor of 5 makes it much easier to adjust the optical and electrical focus when operating the shutter tube equipment under recurrent pulse conditions. Furthermore, the eye is apparently less fatigued by the green light from the Q3-2657 than it is by the blue emission of the 1411 type phosphors. However, the green screen would not be used if its photographic efficiency were much less than that of the blue screen. Exposures of Tri-X and of Royal Pan films to light emitted by green and blue fluorescent screens under the same conditions of electron bombardment show that the combination of Tri-X exposed to the green screen gives 20 percent higher transmission (at densities between .4 and 0.7) than the combination of Tri-X exposed to the blue screen. The reverse is true when Royal Pan film is used, and it happened that Royal Pan and Tri-X both developed to the same density when exposed to the green screen. These results are open to criticism because they are based on few measurements at exposure times (1/2 to 1/200 sec) long compared to the eventual microsecond flashes and with development in DK-50 for the time specified by the manufacturer. However, the results indicate that the gain in photographic response which might be expected from using the blue 1411 type of screen instead of the green Q 23 type will probably be slight. Variations in the phosphor settling procedure or in the aluminizing process can cause changes in the light emitted from the fluorescent screen which are comparable to those already mentioned. (The light output from T.V. picture tubes made in production quantities has an average deviation from the mean of about 10 percent).

The persistence, or decay, characteristics of the fluorescent emission from the phosphor may be an important consideration in specific applications of the shutter tube. The specific application for which this shutter tube was designed imposed no special requirement on the phosphor decay time inasmuch as the high speed system was required to deliver only a total of sixteen pictures and these are displayed on separated areas of the fluorescent screen. For this particular application the

decay time might well be made long in order to minimize the Schwarzschild effect, or reciprocity law failure (Section VI). However, it seemed desirable to design the shutter tube so that a few thousand "bursts" or frames of 16 pictures each could be recorded per second with a high speed film camera such as a Fastax or a Kodak High Speed Camera. To this end the present "P-11" decay was selected. For higher repetition rates the P-15 or P-16 type phosphors will have to be used.

POWDER PREPARATION

In order to eliminate aggregates of phosphor particles as well as the larger size crystals to the phosphor is settled in a 19 inch column of .03 percent gum arabic solution for 20 to 30 minutes after which only the powder suspension remaining in the upper 18 inches of the column is syphoned off into a pyrex bottle. Occassionally a double settling of 15 minutes each has been used with possibly finer screens resulting.

The .02 percent gum arabic solution is prepared by boiling 1,000 cc of deionized water to which 0.3 gram of gum arabic has been added. About 4 drops of potassium silicate (sp.gr. = 1.25) is sometimes added with possibly increased adhesion of the phosphor in the final settling operation. After cooling to 20° to 50°C the solution is vacuum-filtered through a medium porosity (max. pore size 14 u) pyrex glass filter.

Twenty-five milliliters of the filtered solution are added to ten grams of the dry phosphor and effective wetting of the phosphor attained by rolling in a pyrex bottle with pyrex rods ($\approx$ 1 inch long x 1/4 inch diameter) for twenty minutes. No loss in light output has been observed for rolling times less than one hour. 75 ml. of gum arabic solution is added to the phosphor slurry and this mixture poured into 100 ml. of solution already in the 19 inch column (1 inch O.D. pyrex tubing). After 20 to 30 minutes of settling in a darkened area the top 18 inches of dispersion is syphoned off into a pyrex bottle. The dispersion is checked for phosphor concentration (mg. per ml.) and is ready for use in settling onto the fluorescent screen face.

The gum arabic is believed to be a protective colloid for the more finely divided of the phosphor particles (gum arabic is sometimes used in helping to keep the coloring matter in inks in suspension). In fact, both gum arabic and the sulphide powder are negatively charged in water solution as shown by the fact that they both deposit out the positive electrode when a voltage is applied to the separate solutions (a necessary condition for peptized colloid, gum arabic, to protect the suspensoid, the phosphor particles. Gum arabic is preferred to the other organics which were tried, gelatin, caffeine, proprietary dispersants, etc., primarily because of its effectiveness at low concentrations and relative freedom from foaming in dilute "solution". Of course, some of the contribution of the gum arabic to maintain the phosphor particles in separated suspension may be due to the increased viscosity which it imparts to the water. Thus, 0.2 percent potassium silicate solution will keep the smaller particles from settling out in 30 minutes, but to a lesser degree, and obviously its effect is simply one of increasing the viscosity. The charge on the fine phosphor particles may be assumed to be neutralized in the silicate solution. However, it was difficult to obtain fine-grained screens which were relatively free of pinholes when the phosphor mix was prepared in this manner. In fact, a 2 week old mix always had noticeable aggregates of phosphor even after vigorous shaking.

FORMATION OF THE FLUORESCENT SCREEN

The fluorescent screen is formed by settling the required amount of phosphor mix through a barium nitrate and potassium silicate solution. The phosphor settling is performed as follows:

Solution 1) 3 ml of 1.6 percent solution of $Ba(NO_3)_2$ is added to 50 ml. of deionized water (preferably boiled and cooled to room temperature).

Solution 2) The equivalent of 0.28 ml of potassium silicate (sp.gr. = 1.25) is added to 50 ml. of deionized water and mixed with 64 milligrams of the phosphor (these values are for a 3 inch diameter screen faceplate so 64 mg. of powder corresponds to a phosphor density on the screen face of 1.4 mg/cm^2).

Solution 1 is poured into the 3 inch diameter (I.D) bulb first and then the well mixed solution 2 is sprayed into the bulb. The powder is allowed to settle for exactly 30 minutes. This may vary plus or minus 5 minutes depending on the room temperature and on the precision with which the barium and the silicate solutions were measured. At the end of 30 minutes the bulb is tilted about 15 degrees and the slightly gelled liquid syphoned slowly from the bulb. Under these conditions the powder sticks well to the bulb face both when wet and when dry. The screen is dried slowly in an inverted position. The timing of the settling is quite critical inasmuch as the wet adherence of the powder to the glass is insufficient to prevent its sliding if the settling time is too short. And if the settling time is too long a complex barium silicate gel settles out on top of the phosphor. This complex barium compound, containing the heavy atoms of barium, strongly absorbs cathode rays (and indeed near ultra-violet rays). These screens show a granular structure which is apparent even to the unaided eye. Whereas, properly timed screens appear smooth when viewed through a four-power eyepiece on the screen checker. The screen checker is a mechanical pump vacuum system with a lead running up inside the tube whose screen is to be tested, the lead being connected to a high-voltage spark coil. At vacuum pressures of several microns the discharge from the rounded end of the lead is sufficiently rich in electron emission to excite the fluorescent screen.

NITROCELLULOSE FILM

To form a reflective film of aluminum on the fluorescent screen a nitrocelluose film must first be formed on the powder such that it contacts the high points of the phosphor crystals and does not sink too deeply into the crevices between them. The film is initially cast on water which covers the screen to a depth of about 1/32 inch. After an appropriate drying time which enables most of the film solvent to evaporate, the water is decanted from underneath the film and the film and screen are dried in an inverted position. The quantity of film solution used and the timing of the drying time are critical. Too little film solution results in such a weak film that it noticeably sinks into the powder or else it tears readily on decanting. Too much film solution causes swirls in the dried film and these swirls are so strong in themselves that the weak boundaries tear quite easily. Also the swirls are sometimes so thick that a noticeable residue is left after film bake or else on evaporation of the solvent the film is so strong that its surface tension draws the film

away from the edges of the tube. In other words, it shrinks. If the timing for evaporation of the solvent is too short, the film will soak into the powder and it will be useless as a suitable base for the aluminum film. If the timing is too long, the film will become too inflexible and will either wrinkle or tear as the water is poured off from underneath it.

Several film solution formulae were tried with varying degrees of success. The formula (N.3) which was least critical as to timing and quantity of solution is:

1) 2.54 gm. 16 sec. nitrocellulose (R.S. grade)
2) 50. cc. amyl acetate
3) 20. cc. N. Butanol
4) 10. cc. N. Butyl acetate
5) 30. cc. Toluol
6) 5. cc. 2-Ethylhexyl acetate
7) 5. cc. Methyl amyl acetate
8) 1.25 cc. Dibutyl phthalate (plasticizer)

A number 26 gauge hypodermic needle with B-D Yale syringe is used to dispense two drops (250 drops per cc.) of the nitrocellulose solution onto the 1/32 inch thick layer of deionized water which was first carefully poured down the sides of the bulb and flowed gently over the screen (quantity is for 3 inch to 3-3/4 inches diameter screens). During the 3-1/2 ($\pm$ 1/2) minutes of solvent evaporation time, color changes are observed which indicate the condition of the film. The first few brilliant colors quickly disappear and a straw color is seen. This slowly changes to a steel-blue color and as soon as the entire surface, even into the corners of the bulb, becomes steel-blue, the water is carefully poured off by tipping the bulb. The screen and film are dried in a slowly moving current of air and the screen is ready to be aluminized.

ALUMINIZING THE SCREEN

The evaporation of aluminum onto the filmed screen is best performed when the vacuum has a pressure less than 200 x 10^{-6} mm Hg (200 millimicrons). A total charge of 75 mg of pure aluminum wire which is wrapped on a three loop .025 tungsten wire is positioned 5 inches below the screen. The aluminum is evaporated slowly at first so that no particles are sputtered from the heater assembly. The hot tungsten evaporator slowly begin to disappear when viewed through the screen as aluminum is deposited on the nitrocellulose film and the evaporation is continued until the evaporator just disappears when its color temperature is approximately 1200°C. The thickness of an aluminum film deposited in this manner is such that 2500 volt electrons just penetrate it in large enough amount to cause a perceptible fluorescence of the screen.

COMPLETION OF THE SCREEN END

The aluminum deposited on the sides of the screen bulb is cleaned off to within 1 inch of the fluorescent screen with a swab dampened with 5 percent solution of ammonium bifluoride. Potassium hydroxide is preferred but it acts more slowly. The area is carefully rinsed with deionized water. The bulb is circled with wax pencil marks to indicate the edges of the aquadag and of the chrome oxide rings (N 4). The aquadag is applied with a brush to the rotating bulb on the proper areas, a small window being left clear for observation of the barium getter flash near the narrow

end of the bulb. The aquadag coating is air-dried; then the chrome oxide (N 5) is painted onto the glass area between the rings of aquadag and overlaps the edges of the aquadag by 1/8 inch. Two thin coats of the chrome oxide are required in order to achieve suitable uniformity of coating.

The screen bulb is then baked in air at 390°C for 20 to 30 minutes to completely burn off the nitrocellulose film and to drive off the water of crystallization of the potassium silicate binder. When cool, the barium getter is mounted in the bulb and the screen end is ready to be sealed to the electrostatic lens end of the tube.

CONDUCTIVE FILM ON CATHODE FACEPLATE

Two distinct types of transparent conductive film were used in the experimental tubes. A film of pure metal deposited on the glass (11) was first preferred to the iridized coating (12) because of the non-reactivity of the noble metals with cesium, as compared with the reduction of the tin-oxide of the iridized film by the cesium at the temperatures used in processing the antimony-cesium photocathode. However, inconsistent results in obtaining a low resistance base of high transparency (attributed to oxidation by moisture of the evaporated metal, usually palladium, between the time of first deposit and the "curing" time) led to a re-evaluation of the techniques of processing a photosurface which was deposited on an iridized film, and it was found to be possible to satisfactorily process the photosurface at temperatures below 140°C (13) without damage to the resistivity of the film nor decrease in photosensitivity of the $SbCs_3$ photosurface. According to Coltman, 140°C is the temperature at which cesium begins to reduce tin oxide, with the formation of a brown, light-absorbing, less conductive film.

The procedure followed in forming a low resistance film of palladium on the 7056 glass cathode end is very similar to the one described by W.H. Colbert, et. al.,(11).

1) A pressure of 0.1 to 0.4 microns is attained prior to the evaporation of aluminum onto the cleaned cathode glass to a maximum thickness of 100 Angstroms (N 1), the evaporation being discontinued when a perceptible darkening appears on the glass. No darkening of the face was taken to mean that the aluminum had not reached the cathode and a second evaporation was made, even though the possibility that Al_2O_3 had been deposited on the glass was recognized.

2) To ensure complete oxidation of the evaporated aluminum, ultra-violet radiation (long 3653 Å) (N 2) is directed on the cathode glass for two hours. The darkening disappears after this exposure or becomes noticeably less dark.

3) The cathode end is again evacuated to 0.2 micron or lower pressure and palladium is evaporated from a tungsten heater at a distance of 12.7 cm from the cathode face. The resistance between the two 120 degree bands of platinum on the cathode face is measured and the evaporation continued until the resistance drops to 800 K ohm.

4) The evaporated palladium "film" is cured at 360° for ten minutes, or until it reaches a suitably low resistance (sometimes as low as a few hundred ohms).

5) Step 3 was actually the final step, the curing bake being deferred until the electrodes were mounted in the cathode end of the tube and the cathode

end sealed to the fluorescent screen end to complete the tube for the final exhaust and photosurface processing steps. In the final exhaust bakeout the resistance of the palladium should decrease to a few thousand ohms per square and in a couple of cases actually dropped to 200 ohms. However, in too many tubes the resistance rose to megohms per square after the exhaust bakeout. Quite large increases in the resistance of the palladium film were noted during the time between the initial evaporation and the time of sealing the assembled tube on the process pump. The major change occurred when sealing the two ends together on the glass lathe; considerable water vapor condensation was observed to occur near the cathode area even though dry nitrogen was flowing from the cathode end of the tube toward the area to be sealed right up to the last instant of joining the glass. This measure of an increase of resistance from 800 K to several megohms from the time the palladium was deposited to the time that the assembled tube was under the final exhaust vacuum was not, however, conclusive evidence that the palladium film would have a resistance greater than 100 K, say, as the resistance might finally turn out to be less than 10 K. Whether the difficulty in obtaining consistent results was due to a difference in the Al_2O_3 layer on the glass, due to differences in palladium evaporation (2 minute time of evaporation appeared to result in the lowest ultimate resistance) or due to varying amounts of contamination between the time of evaporation and the curing bake during the final exhaust of the assem led tube, is not known at the present time.

One important experiment which was not performed but which might have eliminated the vagaries of the palladium film is to heat the palladium film immediately after it has been deposited on the cathode surface and preferably while it is still under vacuum. An appropriate gradient of heat in the electric oven would permit this to be done without subjecting the glass to undue strains and without heating the rubber gasket seal to the pump. Once the palladium film has been cured to a resistance lower than a few thousand ohms it appears to be extremely stable in air.

In retrospect it appears as though the use of the "adhesive Al_2O_3 base" may actually have complicated the results inasmuch as the resistance readings taken during the evaporation should be lower for a given quantity of palladium evaporated the better the adhesive and uniformity properties of the Al_2O_3. Thus, on the one hand we may have evaporated too thin a layer of palladium to resist "oxidation" and on the other (no Al_2O_3) the edges of the palladium globules (bridged, of course, so as to have a finite resistivity) may oxidize before the curing bake is performed.

The "iridized" semi-conductive film of "tin oxide" was initially formed on the flat glass faceplate prior to sealing the faceplate to the end of the glass cylinder. Only the useful cathode area was iridized.

The preparation of the conductive transparent coating ("iridizing") is based on a procedure recommended by R. Gomer

The glass plate is first washed with Softasilk Liquid Hand Soap, rinsed with deionized water and dried. Then the parts of the plate which must remain uncoated are painted with "aquadag" (Acheson Colloids) diluted with deionized water to binding consistency.

Three Pyrex glass vials 1 inch in diameter, 1-1/2 inches high tapered to an opening of 1/4 inch at the top are filled with $SnCl_2$ $2H_2O$ (Mallinckrodt Analytical Reagent) to a 1/4 inch height. They are placed on a hot plate and the crystal water is driven out and the heating is continued until the calcinated stannous chloride

is molten. A clean surface of stainless steel, 1/16 inch thick, 6 inches in diameter is placed on the hot plate (commercial 660 watt, Nichrome heater 6 inch plate).

The glass plate is placed in the center of the steel disk and the 3 vials are placed around it at 120 degree angles. The assembly is covered by a Pyrex bell jar 6 inches O.D. and 2-1/2 inches high tubulated at the top. The bell jar is covered with asbestos on the outside, leaving an observation window. The tubulation is connected to a low pressure oxygen line. The plate is placed in a hood. The hot plate is heated to a temperature of 500°C (measured on the top of the steel plate). Oxygen is admitted at an approximate rate of 1 liter/min. The stannous chloride vapors deposit on the glass and the process is continued until the plate shows a purple interference color. The bell jar is lifted off, the 3 vials are removed, and the glass piece is cooled with the hot plate.

The aquadag coating is removed with a brush and deionized water. Then 2 semi-circular platinum bright electrodes are painted at the edges of the iridized portion and the plate is rebaked at 550°C for 15 minutes in an electric oven.

It was noted that optimum resistivity (less than 1000 ohms per square) was also accompanied by optimum transparency (greater than 88 percent).

ELECTRODE TREATMENT

The accelerating and focusing electrodes are all machined from 304 stainless steel pipe (N 1). The edges of the electrodes are all rounded and polished with crocus cloth. Electrolytic polishing methods were briefly tried but never applied to many electrodes as discharges between adjacent electrode ends occurred in only three tubes (when proper voltages were applied to the electrodes).

After machining, the 304 electrodes are degreased and fired in hydrogen (cracked) ammonia gas is actually used) at 1070°C for 15 minutes. Several tubes were successfully made using only H_2-fired electrodes but where practical we preferred to also further degas the electrodes in vacuum to about 1000°C. Remanent magnetism of the 304 electrodes is apparently extremely low, its effect being not noticeable in the image.

A few electrodes were gold-plated with the three-fold objective of decreasing internal light reflections (blue light reflectivity of gold is low), decreasing the photoemission of those electrodes which "see" the antimony evaporation by process of "dilution", the decreasing emission or spark-over between adjacent electrodes. The results were negative -- no marked changes in the behavior of the gold-plated electrodes from the unplated ones were observed.

Several tubes were constructed in which the inner surface of the electrodes was coated with a black carbonaceous deposit (N 2). This black coating was quite adherent to the 304 metal and apparently was good vacuum material. Internal light reflections were obviously reduced and the fluorescent images appeared to have better contrast. The photoelectric emission from the electrodes was reduced in most tubes (ascertained by biasing the grid mesh negative and shining light on the other electrodes). However, these tubes showed the "cross-over" effect (Section II) to a somewhat greater degree than the tubes not having the coating. If the "cross-over" effect is due to secondaries liberated from the electrode walls, an investigation of the s/p ratio of this surface is in order; but time did not permit this work to be performed under this contract.

While investigating the photoemission from the grid mesh bars, it was found that no emission was occurring from the aluminum rivets holding the mesh rings together. The antimony apparently diffused into the aluminum during the cesium bake of the tube. Therefore, aluminum was evaporated onto the mesh of a recent tube (along with some tin). The suppression of emission was not complete but apparently had some effect. The tube #2-7-55 has aluminum on the cylinders exposed to antimony evaporation and on both sides of the mesh (to thickness estimated to be about 1 micron). On side of mesh facing photocathode is evaporated layer of gold (to reduce blue light reflection back at cathode).

PHOTOSURFACE PROCESSING

The emission of photoelectrons from a material occurs in the outer atomic layers of that material. In other words, it is primarily a surface pheromenon -- photoelectrons emitted too far below the surface not being able to excape through the atomic layers above them. It has been reported in the literature that the 100 atomic layers closest to the surface are the only layers which contribute electrons to the measured photoemission current. Experimentally, it has been determined that the thinnest layer which will still give conduction between two platinum contacts (Pt Bright) will have the highest photosensitivity to light (2870°K tungsten source) transmitted through the layer when the photolayer is deposited on Pyrex glass. Therefore, it is obvious that all sources of contaminating gases or materials be eliminated from vacuum tubes containing photosensitive surfaces. Some of the procedures for ensuring contamination-free parts in the tube have already been mentioned. The vacuum bake of the assembled tube prior to processing the photosurface is, of course, an essential part of the cleaning procedure. Equally important for photosensitive stability is the activation (or cesiation) procedure whereby steps are taken to ensure that no free cesium be left on the tube parts to migrate at some later date to the photosurface. A detailed summary of the steps taken to process an $SbCs_3$ photosurface follows:

1) The tube is vacuum baked for 1 hour at 300°C (N 1)

2) Upon cooling to 170°C, the Cs pills, Ba getters, Mn evaporator, Sb evaporator are degassed and the aluminum evaporated across the glass gap at the junction of the two halves of the tube.

3) 300°C bake is continued for two or more hours until the vacuum gauge shows a pressure less than 1.5×10^{-6} mm Hg (at 100°C or lower the gauge should show p _ 10^{-6} mm Hg).

4) After the tube has been cooled to room temperature, manganese ( ) is evaporated to a relative transmission of 78% as measured with a semi-transparent $SbCs_3$ photocell (light source color temperature about 3000°K).

5) The manganese is oxidized by scanning a wand at R.F. (100 kc) potential over the surface as oxygen is admitted to the tube to the proper discharge state. The transmission rises to about 90%.

6) The oxygen is pumped out and pumping continued at room temperature for twenty minutes (N 3).

7) The cesium pills are flashed and then the barium getter is partially flashed to ensure thorough outgassing.

8) Antimony is evaporated to a relative transmission of 80% -- somewhat thicker than the optimum of 85% -- as measured with an S-9 photocell.

9) The cathode and anode (grid mesh) connections are made to the appropriate terminals of a D.C. amplifier-recorder unit which records currents from 1 microampere full scale to 250 microamperes full scale. Wet asbestos (1/8" thick pack of 5 layers) is lightly tapped against the cathode glass, and the oven is placed over the tube assembly.

10) After a 15-20 minute bake at 140° - 170°C (N 4) the oven door is raised and cesium is torched in until photosensitivity becomes apparent. The wet asbestos is removed from the cathode face and torching of the cesium continued until most of the antimony has been cesiated (the practically invisible antimony film becomes a visible straw-brown turning to red when properly cesiated).

11) Wet asbestos is replaced on the cathode face and baking resumed.

12) Baking at 140°C is continued for 5 to 15 minutes or until all visible traces of cesium have disappeared. The photocurrent is monitored during this stage - with the light shining through a window in the oven and through the gaps between the electrodes to illuminate the internal or "front" photosurface.

13) The wet asbestos is removed from the cathode face and baking is continued while the photocurrent rapidly rises toward a maximum.

14) When the photocurrent approaches a maximum (i.e. the rate of rise of the current decreases substantially), the oven gas is shut off and the tube allowed to cool slowly. In about 8 minutes the termperature is down to 90°C and the photocurrent will start rising when the cesiation and bake have been just right.

15) The oven is removed from the tube at a temperature of about 80°C and the photosurface is fan-cooled and monitored. If the photocurrent rises further and its sensitivity is 10 to 20 ua per lumen at room temperature, steps 16 et seq. are followed. Otherwise, a return to step 11 or to step 10 is needed and at this point the judgment of the operator (based on the continuously monitored record of the photoemission and baking cycle) is all important in deciding what to do. Fortunately, steps 10 to 15 may be repeated several times without greatly reducing the final sensitivity below 30 ua/l. (N 5).

16) When a photosensitivity of 10 to 20 ua/l has been obtained and the operator is reasonably certain that the red antimony-cesium compound has the right proportions ($SbCs_3$ plus slight excess of cesium) oxygen is admitted from a flask of spectroscopically pure oxygen through the ceramic diffusion valve. The pump continues pumping at full speed. With proper surface conditions the $SbCs_3$ photosensitivity will rise to two to four times its initial reading during admission of the oxygen.

Generally the oxygen is admitted in small doses until the sensitivity rises to 25 ua/l if this value is more than twice the initial sensitivity or to twice the original sensitivity.

18) If within 5 minutes after the barium flash the photosensitivity has not risen to its original value, or higher, oxygen dosing is continued until the photosensitivity no longer rises with dosage.

19) Pumping at room temperature is continued for 5 to 10 minutes, still observe the photosensitivity changes if any, and then the tube is tipped-off the pump.

It would be highly desirable to avoid the use of the external cesium source. But the 2" tubes would not accommodate a large enough source and the larger tubes were constructed so late in the contract period that time was not available for this experimentation.

Figure 30. shows a shutter tube during exhaust processing.

CAMERA OPTICS

Although the primary aim of this contract was to devise a high speed shutter system capable of recording sixteen pictures at the rate of 500,000 times per second, a secondary aim was to achieve a light gain from the system so that exposure times could be shortened for a given source of illumination or the source's light flux could be reduced. As was already noted, at a 1:1 fluorescent "image" to photocathode "object" ratio light gains of a factor of 20 are attainable (   ) with the camera tube and at a 1:4 image to object ratio a gain of 80 times should be attained. However, in focusing the light from the screen onto the photographic film, considerable light flux is lost so that the overall gain of tube plus camera is decreased by a factor of 10 to 25 when standard refractive optics is used in the photographic camera. Consideration of this fact was made before the contract began with the assumption that an F/0.75 lens would be used. However, F/.75 lenses are costly and no decision could be reached as to the image to object ratio which would ultimately be required until the fluorescent image size had been standardized (and the image is a function of phosphor particle size, resolution required from the image in lines per millimeter, and camera resolution - including film grain size).

Therefore, due to the interrelated factors influencing the choice of a lens with the proper focal length, the decision to use a particular lens and to design the tube to fit the lens was postponed. Schmidt reflective optics was also considered but this also would have required a tube built to fit the optics instead of vice versa. (The tube was considered to be the most important part of the system and as such should not be restricted in its development by too many external considerations, as actually happened by limiting the tube development to a deflection yoke of inflexible dimension). When a 1:1 photographic "image" to fluorescent "object" was finally decided upon, it was found that most lenses would not produce well defined images inasmuch as they were not designed for such short conjugate work. In fact, for optimum resolution a lens must be designed (and corrected) for the image-object ratio to be used. And so, the original apprehensions about using an F/.75 lens of fixed (5") focal length were justified. Future efforts to improve the light gain of

the high speed shutter system should, therefore, involve the design of the photographic camera to couple efficiently with the light emitted by the fluorescent screen of the shutter tube. (N 1)

CALCULATIONS OF CAMERA LENS EFFICIENCY

A_1 = area of object source, the fluorescent screen

L_1 = luminance of screen in candles/ft^2

E_1 = equivalent illumination of the fluorescent screen in foot-candles

= coefficient of reflectance of A_1 (Lambert distribution assumed)

= angle subtended by one-half of lens diameter

f = focal length of the lens

F/No. = f/D

A_2 = image area

m = linear magnification image to object = $\frac{A_2}{A_1}$

E_2 = illumination of the image area in footcandles

Assuming Lambert law of emission of light from the fluorescent screen

Light flux from A_1 filling lens is = $A_1 L_1 \quad \sin^2$

since $L_1 = \frac{E_1}{\quad}$

for $\quad = 1$

1) Light flux from A_1 filling lens is $E_1 A_1 \sin^2$

2) Light flux from A_1 on $A_2 = E_2 A_2 = \quad E_1 A_1 \sin^2$

where

$$\sin \quad = \frac{D/2}{f(m+1)} \text{ (approx) and } = \frac{m}{2\ F/No.\ (m+1)}$$

and

= transmission of the optics.

Eq 2) becomes

$$3)\quad E_2A_2 = E_1A_1 \left[\frac{m}{2F/No.\,(m + 1)}\right]^2$$

Assume

= 0.8 (coated-glass optics is often not this good)

$$\frac{A_1}{A_2} = \frac{1}{m^2}$$

then

$$4)\quad E_2 = 0.8\, E_1 \left[\frac{\;}{2\ F/No.\ (m + 1)}\right]^2$$

At small values of m, the object is far from the camera, and the illumination, E_2, on area A_2 is 0.2 $\frac{E_1}{(F/No)^2}$. Therefore, the camera can be said to have an efficiency of 20% if the lens is F/1, 36% at F/.75, and only 5.5% at F/1.9.

For unit magnification (m = 1), equation 4 shows that the illumination on A_2 is one-fourth the value it would have for small m. Therefore, at unit magnification (or close to it) even extremely fast F/.75 lens is only 9% efficient and the light gain obtained with the high speed shutter tube is reduced by a factor of 11 in "projecting" the light from the fluorescent screen onto the photographic film. It would thus appear desirable to work with m much less than unity. However, the fast photographic films presently available have a resolution of about 35 line pairs per millimeter so the film will begin to limit the overall system resolution if the image on the film is made smaller than 10 mm, say, on a linear dimension, and 10 to 15 mm on a vertical and horizontal dimension has been determined to be the size of fluorescent screen "object" required to give (at the screen) a resolution of 350 to too lines (television line definition).

One way out of the dilemma (   ) of not having commercially available lenses designed for short conjugate operation as well as the high losses entailed with such use was to use two lenses, each operating at "infinity". The efficiency of this combination for F/1.9 lenses is then approximately 4.4% allowing 0.8 transmission factor for the second lens) at 1:1 ratio. Note that this efficiency is 90% of what could be expected from a single F/1 lens operating at unit magnification. It was found that two F/1.9 Cinema Raptar Projection lenses of 5" focal length operated "back to back" covered a 3" diameter circle with a gradual film density loss away from the axis of the lens system.

Figure 32 is the plot of the measured density as a function of the distance from the center at a magnification of 1:1.

PHOTOGRAPHIC FILM AND DEVELOPMENT

The problem of the photographic film to be used for recording the microsecond, and shorter, flashes on the fluorescent screen could easily be made by itself the subject of a research project. However, some knowledge as to film behavior to short light flashes, to the color of the light, to the process of developing, etc., had to be gained in order to be certain that good use of the available light was bing made.

Tri-X and Royal Pan panchromatic films have been used in taking most of the pictures of the fluorescent screen "images". Their relative response to the color of the light emitted by the fluorescent screen has been discussed in Section G. The development of the film in DK-50 or D-19 for extra long periods of time (15 minutes for force development) produced extremely grainy negatives. Nevertheless, D-19 and 15 minutes developing time was used for both types of film.

Some loss due to reciprocity law failure for short duration flashes is present (   ), but a long exposure of the entire film area to low intensity illumination after the short flash of light is said (loc. cit.) to change most of the "sub-image" formed during the flash into a true latent image which is developable by regular methods. Therefore, reciprocity law failure will not be considered further, although it is a factor to be considered in a more complete analysis of short duration photographic exposures. Hypersensitizing (as by bathing in an ammonia solution) of the photographic film was not tried during the contract period.

The Eastman Kodak Company sent a sample length of 35 mm Type I-D film which has a sensitization curve closely matching the light output spectral curve of the Q3-2657 phosphor, but all pictures made during the contract were on 4 x 5 film pack.

MEASURED VALUES OF LIGHT FLUX (1/100 SECOND EXPOSURE TIME) TO PRODUCE A USEFUL DARKENING OF TRI-X PANCHROMATIC FILM.

Using two f/4.7 5 inch fl. lenses in front to front at 1:1 ratio, one-third (1/3) blue lumen (   ) from a 1-1/4" x 1-1/4" area produced a density of 0.76 in Tri-X film at 1/100 second exposure (normal development in DK-50 was used). (states "according to T. Dunham, Jr., the two requirements for adequate detection and measurement of weak absorption lines are a minimum density of 0.6 and sufficient contrast").

Assuming that the two f/1.9 lenses had been used, then only $1/3 \times \frac{(1.9)^2}{(4.7)^2} = .054$ lumens would have been required (glass transmission losses assumed to be the same.

At 1 usec exposure the light flux will have to be 10^4 times greater (neglecting Schwarzschild effect) or 540 lumens from the $(1\text{-}1/4")^2$ area.

Or, $540 \times 92.2 = 50{,}000$ lumens/ft.^{2} = 5×10^4 ft-candles of illumination is required from the fluorescent screen to produce a density of 0.76 on the film (using two f/1.9 lenses).

With a light gain of a factor of 100 in the shutter tube, a peak illumination level at the photocathode of 500 ft-candles will be required for recording the microsecond exposure

CALCULATIONS OF MINIMUM LIGHT LEVEL AT PHOTOCATHODE OF HIGH SPEED SHUTTER TUBE

Assumptions:

1) 10^6 quanta required at photographic plate on a 0.1 mm diameter element (according to W. Baum of Mt. Wilson and Palomar Observatories) to produce a measurable density.

2)

2) resolution of screen is 20 line pairs per millimeter so elemental area is .02 mm diameter and 4×10^4 quanta are required at each elemental film area.

3) 5% efficiency in the optics

4) 400 quanta are emitted per 20 KV electron from an efficient phosphor.

5) photocathode elemental area is 4 times the fluorescent screen elemental area.

Then $\frac{4 \times 10^4 \times 20}{400} = 2{,}000$ electrons are required from the elemental photocathode area (.04 mm diameter) to produce a measurable density at the photographic plate.

6) If these 2,000 electrons were emitted in one microsecond, a peak current of

$$i = \frac{1.59 \times 10^{-19} N}{10^{-6}} = 3.18 \times 10^{-10} \text{ amps or } 3.18 \times 10^{-4} \text{ microamperes would be}$$

taken from each illuminated elemental area on the photocathode.

7) assuming 40 ua/l photosensitivity, then 0.8×10^{-5} lumens will be required on each .04 mm element,

or

8) 600 lumens/ft^2 = 600 foot-candles

$$9.3 \times 10^4 \frac{mm^2}{ft^2} \text{ and area each element} = .00125 \text{ mm}^2$$

These calculations are admittedly based on a number of assumptions which may be in error by a large percentage. However, the agreement between the illumination levels determined by two quite different sets of calculations leads one to suspect that the required illumination level at the photocathode will be somewhere in the neighborhood of 550 foot-candles for a 1 usec film exposure using 2 - f/1.9 lenses and a shutter tube gain of about 100.

It is rather gratifying to note from photograph Fig. D6, that the illumination actually required to record with 1 usec exposures and at a density of .5, was only approximately 500 foot-candles (from a projection lamp operating close to the color temperature of 2870°C) at a shutter tube gain of only 33 and at a recording camera aperture ratio of f/3.8. (With an f/1.9 lens an illumination of approximately 200 foot-candles would give satisfactory negatives).

Calculations of the light level required by existing storage tubes indicate that only the image orthicon could operate with a lower light level and that this level of 3 to 23 foot-candles is limited primarily by the fluctuation noise of the electrons emitted by the few quanta arriving during the 1 usec exposure time.

The work described in the preceding sections was done by the Syntronic Instruments, Incorporated, Addison, Illinois under subcontract to the Rauland Corporation. Dr. Henry O. Marcy, who was in charge of the project, has written the following portion of the report.

SWEEP CIRCUITRY

Introduction

At the outset of the project it was recognized that the circuit problems would be largely sweep problems. Very high instantaneous sweep speeds and very rapid "settling" time after the sweep has reached the correct displacement are necessary to meet the requirements of exposures separated by only 1 microsecond. During this 1 microsecond the shutter tube must be blanked, the sweep started, stopped and time allowed for "settling" before the shutter tube is turned on for the next picture.

Magnetic deflection was chosen because it was felt that simpler shutter tube gun structure and better final picture resolution would result. Electrostatic deflection plates add to the difficulties of electron optics design. It was decided to avoid this complication. Calculations of the sweep power involved showed that magnetic deflection would not be more of a problem than electrostatic deflection at the proposed potentials. We must consider that the shutter tube has an electron beam of large cross-section in comparison with ordinary cathode ray tubes. Therefore, the spacing of the deflection plates would have to be greater than is found in typical oscilloscope tubes. This together with high accelerating potentials in the vicinity of the deflection plates requires high sweep voltages. The latter make it necessary to use transmitting tubes for electrostatic deflection as well as for magnetic deflection.

To reduce the sweep rates a zig-zag type of scan has been used. Sixteen pictures were chosen. The first picture is deflected simultaneously up and to the left 1.5 picture widths. This is the maximum displacement of the sweep. Thereafter for each successive picture there is a displacement equal to 1.0 picture width either in the horizontal or the vertical direction. The sweep progresses successively three jumps to the right, then down one jump, then successively to the left, down again, then to the right, then down to the last row and finally to the left. The last picture is at the left of the bottom row.

This scan requires the same performance from the horizontal and vertical sweeps. The wave form applied to the vertical amplifier is easier to generate, but the slope of the vertical steps must be as fast as required by the horizontal sweep. Therefore, both sweep amplifiers are identical and the deflection yoke is symmetrical.

Sweep Amplifier

A push-push type of amplifier has been used to take advantage of the relatively low duty cycle expected for the picture sequences. An arbitrary limit of 25% was set for this duty cycle. Thus a recovery period three times as long as the total

time required for the sequence of sixteen pictures must be allowed to prevent the driver tubes and power supply of the sweep amplifier from becoming over-rated. The sweep amplifier schematic (drawing #B1219) shows the circuit details. A push-pull yoke is used to allow deflection in either direction, but both sets of driver tubes are at cut-off when the beam is undeflected. To deflect to the left V5 and V6 are made conducting. To deflect to the right V7 and V8 are conducting. Parallel 6BG6G's were chosen as giving the greatest plate dissipation of the common commercial tetrodes. A cathode follower is used to drive the grids approximately 15 volts positive for extreme deflection. One triode section of a 6BQ7 and a 6CL6 pentode are used for gain in the amplifier. Feedback is from the 6BG6G cathodes to the corresponding input cathodes. In effect the horizontal sweep amplifier is split into two independent amplifier sections, one for deflection to the right and the other for deflection to the left. Because the scan required is discontinuous, this circuit discontinuity in passing from right to left sections causes no difficulty. Figures M4, M6, M8 and M10 show Synchroscope pictures of the 6BG6G cathode waveforms. The choice of yoke inductance and the problems of rapid settling are discussed in a later section entitled Yoke Design. The amplifier must have sufficient deflection current available for a suitable yoke. Measurements on the amplifier shown in drawing B1219 indicate a maximum available peak current of 0.9 amperes. Experience has shown, however, that deterioration of the 6BG6G cathodes shortens the life of these tubes when such large current pulses are used.

Waveform Generation

To generate the scan discussed previously a staircase waveform must be introduced to the horizontal and vertical amplifiers. A series of trigger pulses initiating each picture is first produced. The time separation of these trigger pulses will be the time separation of the pictures in the sequence. It was felt that this should be easily varied in order to increase the versatility of the equipment. By the use of two circuits, adding circuits and mixers these trigger pulses form the step type waveforms required.

Not only must a burst of correctly timed trigger pulses be generated but the repetition rate of this burst must be variable from a single burst (zero repetition frequency) up to as high a frequency as the 25% duty cycle of the sweep amplifier permits. Drawing C1037 shows a circuit schematic for the generation of a sequence of trigger pulses. V7 is a gate which shock excites the Hartley Oscillator, V8. V9 and V10 form a regenerative amplifier of the flip-flop type and V11 is a blocking oscillator trigger generator. Switching of the tank circuits of the Hartley oscillator allows a coarse variation of the spacing of the trigger pulses. Slug tuning of the tank circuits allows fine control. The whole circuit is designed for high speed with a maximum oscillator frequency of 500 kilocycles and a trigger pulse width of approximately 0.1 microseconds.

Synchronization

The gate, V7, is started by the appropriate synchronizing trigger. It is shut off automatically after sixteen trigger pulses. This shutoff trigger is obtained from the shaper as shown in drawing C1357.

To synchronize the sequence of trigger pulses there are three modes of operation. Position one of Switch 1, drawing C1037, is for internal triggering from the blocking oscillator V3. A positive trigger output is provided to synchronize external

equipment. V1, V2, and V3 provide a variable delay between the external trigger and the start of the gate, V7.

Position 2 of Switch 1 provides for external triggering from a positive trigger with the same delay before the start of the picture sequence as before.

Position 3 of Switch 1 provides for a single shot sequence from a positive trigger or triggers. Resetting is done by means of Switch 2. A difficulty in the reset circuit was experienced because of the mechanical nature of Switch #2. If the input positive triggers are at a frequency high compared to the action time of the switch two or more bursts will result instead of the single sequence desired. To prevent this a long recovery period has been introduced into the trigger amplifier and blanking circuit described under the section entitled Blanking Circuit.

The remaining circuit V5 of drawing C1037 is to provide a bias gate for the sweep amplifier. This gate has to be somewhat longer than the oscillator gate to allow for the positioning and exposure of the 16th picture. The oscillator gate on the other hand, must shut off quickly, after the 16th trigger to prevent an extra trigger. An RC integrating circuit in the grid circuit of the inverter prolongs the end of the gate by a constant time interval.

Shaper

Starting with a sequence of 16 trigger pulses drawing C1357 shows the circuits employed to form the horizontal and vertical staircase pulses. Four successive scales of two circuits each using a pair of 6C16 pentodes provide the basic gates from which the correct waveforms are made by addition. Paraphase inverters and cathode followers are used to provide the four sweep signals required by the sweep amplifiers. A block diagram of the synchronizer and the shaper circuits (drawings C1037 and C1357) is shown in Fig M1. The waveforms corresponding to various points shown on the schematics and the block diagram are shown in Fig M2.

It should be noted that all circuits are d-c coupled so that the operation of the sweeps is independent of the interval between pictures or the repetion rate of picture sequences. Since this d-c coupling involves as many as six successive stages up to the sweep inputs without any stabilizing negative feedback, it can be readily appreciated that the circuits are quite critical to changes in power supply voltages. Although all supply voltages to the shaper are regulated, this is an inherent weakness in the circuit design.

It will be observed from the waveforms shown in Fig M1 that during the interval between picture sequences a bias gate must be applied to the sweep amplifiers to prevent conduction of the driver tubes. It is in fact this bias beyond cutoff for a majority of the time which allows the use of receiving-type power tetrodes in a circuit requiring such high peak power for deflection. Otherwise the plate dissipation of the tubes will be exceeded. This bias gate is obtained from V5 of the timer chassis (drawing C1037) described above. It is introduced into both the horizontal and vertical staircase circuits.

Although the vertical staircase is obtained readily by the addition of two gates using the adder circuit V16, it is more difficult to obtain the horizontal staircase. The latter requires the addition of three gates. The result is then compared with the inverted staircase in the non-additive mixer V21. The output of

this cathode follower mixer reproduces whichever input waveform is the more positive. The sweeps require four separate inputs for up and down, left and right. V17 inverts the vertical staircase and V20 inverts the horizontal staircase. Cathode followers V19 and V20 are used to adjust the d-c level of the sweep inputs as well as provide a low impedance. The also allow easy mixing of the bias gate described above.

The automatic shut off is generated in V18. This tube is normally cut off. It becomes conducting only when the vertical and horizontal staircase waveforms are correct for the last picture. The inputs to the shut off are taken directly from the adder tubes V14 and V16 so that any adjustment in sweep centering or amplitude will not affect the shutoff. The output of the V18 is fed back to the master gate of the synchronizer described above. This gate must be cut off immediately after the 16th trigger pulse to allow time for the oscillator circuit to be squelched or a 17th trigger will be generated causing an extra picture, upsetting the bias of the sweep circuits and over-rating the sweep driver tubes.

Faults of the Circuits

Although it was originally expected to encounter severe difficulties in the sweep amplifier and yoke design, this problem turned out to yield to a straightforward approach. At present the yoke speed is not as great as desired but a redesign of the circuit to provide a greater peak deflection current will produce a proportional increase in deflection speed. As described below, the settling time of a yoke is least for critical damping or very slightly under critical damping. The time to settle to 0.2% of the sweep is then 1.2 x the resonant period of the yoke. This assumes that the time constants in the magnetic circuit about the yoke, specifically the core time constant and the case time constant, may be compensated. The latter has proved practical. The present yoke has a resonance of 500 kilocycles when hooked up in the final circuit. This includes the lead capacities, capacities from the yoke itself to the shutter tube, etc. A resonance of approximately 1.2 megacycles is needed to meet the original specifications for the project. The sweep amplifier should provide 2.4 times the present current to accomplish this since a further reduction in yoke and stray capacities will be difficult.

Far more trouble has been encountered in forming the staircase wave forms in the shaper. A good portion of this can be attributed to the imperfections of the scale of two circuits. Accurate measurements show that the gates are not perfectly flat, but have slight drifts which could blurr the longer exposures of the pictures. This has been reduced by increasing the stiffness of the counting circuits. Diode clippers were also tried but reduced the amplitudes of the gate to the point where other problems were encountered.

More serious in its consequences is the difference between the positive slope and the negative slope of the gate. The staircase generator adds together positive and negative gates for some of the picture positions. Therefore a difference between the positive and negative slopes will generate a troublesome transient. This transient is then integrated by the sweep amplifier and yoke causing blurring in several of the pictures where short intervals between pictures are used. The horizontal staircase with its greater complexity is far worse than the vertical. The synchroscope pictures of Figs M3-M10 show the staircase waveforms of the four shaper outputs together with the corresponding voltages across the cathode resistors of the 6BG6G driver tubes of the sweep amplifier. The latter are proportional to the deflection yoke currents. Note the severe transients that occur in both horizontal staircase

waveforms (Figs M3 and M5). Fig M11 shows a sequence of sixteen pictures on the shutter tube where blurring of the pictures occurs as a result of these transients. Note that the first picture is blurred in both horizontal and vertical directions as a result of the greater initial sweep amplitude. The fifth, ninth and thirteenth pictures are blurred only in the horizontal direction as a result of the transients occurring in the horizontal input staircase voltages. To get this picture the delay between the start of the sweep and the shutter pulse was reduced to 1.5 microseconds. A 0.3 microsecond exposure was made of each individual picture.

Finally, it is quite apparent that the signal amplitude of the horizontal sweep inputs is insufficient. The signal is limited by adder circuits V14 which must always operate in a region of reasonably good transconductance. The circuit of V21 cuts this amplitude to less than half and the establishment of correct d-c levels causes a further reduction. Since shifts in d-c levels are caused by variations in either positive or negative supplies the stability is poor. Perhaps worse yet is the reduction in allowable feedback and freedom from drifts in the sweep amplifier due to a small signal input.

<u>Suggestions for Improvements</u>

Several methods of overcoming the faults discussed above are available.

1. Extra sweep power can be obtained by the use of more driver tubes in parallel or by a change to transmitting tetrodes. The RK-4D32 is an example of a huskier driver tube.

2. The staircase waveforms may be developed from the scale of two circuits by the use of coincidence circuits and separate gate generators. Only addition of positive gates would then be required. This would eliminate the addition of a negative to a positive gate which produces the troublesome transient described above.

SHUTTER PULSE GENERATOR

The shutter pulse must be delayed approximately 2 microseconds from the initiation of the sequence or burst of 16 trigger pulses generated by the synchronizer as described above. This delay allows the picture position to be shifted and the sweep to settle. An ordinary fast gate employing two 6CL6 pentodes, V2, and V3 is used. The circuit schematic is shown in drawing C1229.

After the appropriate delay another double pentode gate, V4 and V5 forms the pulse width desired. A three-position switch and a potentiometer allow this gate to be varied over a wide range. The output gate taken from the cathod of V4 is fed into the cascade video amplifier consisting of V6, V7, V8 and V9. By overdriving the amplifier, V9 is cut off and the plate of V9 returns to ground from a negative point. It is this positive pulse that is fed to the shutter tube grid. The symmetrical arrangement of the amplifier is used to balance the power supply load. No use is made of the negative pulse available at the plate of V8. This pulse will not be identical in timing with the pulse at V9 since the amplifier is overdriven and the push pull balance for video signals destroyed.

Assuming that the gain of the amplifier circuit is sufficiently great, V9 may be considered to cut off instantaneously. The rise of the pulse will then depend only on the RC time constant of the plate load resistance (450 ohms in this case) together with the shutter tube grid and stray capacities. Since the plate is returned to

ground the top of the pulse will be flat and its potential accurate. D-c coupling to the shutter tube grid is practical. We may assume that the current available from V9 is limited by tube ratings such as permissible cathode current and plate dissipation. Greater amplitude will be obtained with more resistance in the plate circuit, but the rate of rise of the pulse will also be slower. A compromise of 60 volts for the pulse height was finally selected.

It is well to note one characteristic of the shutter pulse generator. If an exposure is selected which is longer than the interval before the next trigger pulse, counting of the shutter pulses will occur and only half the pictures will be exposed. There is, however, an inherent tendency in the gate circuit forming the shutter pulse to flip over with the new trigger pulse. This tends to prevent counting, but also prevents accurate calibration of the shutter pulse controls.

DEFLECTION YOKE DESIGN

The design of the deflection yoke is a modification of Syntronic Instruments type Y36-AA5P. Drawing C1688 shows mechanical dimensions and electrical characteristics. This type of yoke uses a mu metal laminated square core. The mu metal has no measurable residual magnetism and low losses. The windings are pie wound to reduce capacities and distributed for optimum resolution of the electron beam. This combination of square core and properly distributed windings gives the best focus of any general type of design. The square core has the further advantage of allowing the yoke to slip over obstructions such as tip-offs and leads which may project out from the cylindrical glass tubing of the shutter tube. The yoke can usually be rotated to allow these obstructions to fit into the corners.

The particular yoke problem in this project involves the movement of a spot rapidly from one position to the next. Not only must the peak sweep speed be high but rapid settling to fixed value is required. The peak sweep speed is dependent largely on the plate supply voltage available for the yoke driver tubes and the resonant frequency of the yoke. If the induced voltage $L\frac{di}{dt}$ is sufficiently great during the start of the sweep the plate will become lower than the screen causing effectively an overdamping of the yoke. Practically, $L\frac{di}{dt}$ will never reach a value greater than that which will reduce the plate slightly below the screen of the driver tube. Of course, the fastest sweep speed can only approach the resonant speed of the yoke even if not voltage limited.

After the spot has been deflected to the new position the sweep must be stopped. Critical damping of the yoke will allow settling to 0.2% of the deflection shift in a time approximately equal to 1.2 x the period of the yoke. Usually the damping is adjusted to a value slightly less than critical damping to obtain the most rapid settling.

Besides the problem of damping the resonant frequency there are two time constants to contend with. These arise from the eddy current losses in the core and in the case of the yoke. The core time constant is approximately 30 microseconds and the case time constant 1200 microseconds. Each effect has an amplitude about 2% of the deflection shift. Since the time constants are long only a long exposure will make them observable on the pictures. Several methods of compensation are available if required.

The particular yoke used has a resonance of 500 kilocycles when hooked up in the circuit. The inductance is 0.7 mh per plate, the resistance 3.2 ohms and the total capacity per plate 145 micromicrofarads. This yoke uses finer wire than usually found in a yoke design in order to reduce the coil capacities. Actual comparisons with other yokes of the same type shows about a 30% reduction in effective capacity. This fine wire is satisfactory in this application since the low duty cycle of the sweeps prevents excessive heating.

BLANKING CIRCUIT

Because there is a small but continuous photoemission from the shutter tube mesh and successive electrodes there will be a spurious image in the center of the shutter tube screen. This spurious image cannot be cut off by the control grid. For single shot exposures where the duty ratio of the desired pictures is small this image is objectionable. An effort has been made to deflect the unwanted picture magnetically. To do this a large deflection yoke with deflection in only one direction was constructed.

Details of design and electrical specifications of this yoke are shown in drawing C1687. The location of the yoke on the shutter tube neck was determined by trial. No position was found which was completely satisfactory since secondary electrons from successive electrodes are formed as the spurious image is deflected into the apertures and electrodes forward of the deflection yoke. These secondaries form a series of concentric rings which are deflected in the same direction as the image. Segments of one or more rings are usually present whenever the spurious image has been deflected off the screen. A compromise position with the center of the yoke 4 inches forward of the photocathode was selected.

A separate chassis to supply the current for the blanking yoke is shown schematically in drawing B1554. To unblank the yoke a positive trigger fires the 2D21 thyratron. The resulting positive trigger from the cathode of the 2D21 is inverted and triggers a multivibrator which determines the length of time the yoke is unblanked. The negative gate from this miltivibrator cuts off a 6BQ6G. Approximately 50 microseconds after the input trigger must be allowed for the blanking yoke to settle before the first picture. This delay is provided by the sawtooth delay circuit, V4, in the synchronizer chassis, drawing C1037. A potentiometer in the grid circuit of the 6BQ6G is provided to vary the blanking current in the yoke.

The purpose of the 2D21 thyratron circuit has no relation to the blanking. It is provided to prevent a too rapid recurrence rate of triggers. There is a long recovery period after the thyratron has been triggered before it can be triggered again. This feature is especially useful in preventing multiple triggering from the transients present in most mechanical switches. It allows the use of a mechanical reset switch in the synchronizer chassis. For this latter operation the trigger from the equipment under observation is fed into the blanking chassis, drawing B1554, and the output trigger from the 2D21 is fed into the synchronizer chassis, drawing C1037.

FLASH LAMP PULSER

For observations with a synchronized pulsed light source the circuit shown in drawing EX 21339 was constructed. A variable delay gate V2 is triggered from the master positive trigger after inversion by V1a. This delay may be made shorter or

longer than the delay in the synchronizer chassis. It is, therefore, possible to start the light source before or after the first frame of the sequence of sixteen pictures. V1b is a blocking oscillator triggered off the back edge of the delay gate. It provides a stiff trigger to fire the 4C35 hydrogen thyratron. The lamp is placed in the cathode of the 4C35. A pulse network in the plate provides a high peak current for a time determined by the network constants. Variation of the voltage and network constants give ample control of brightness, duration, and rate of rise of the brilliance with time.

REFERENCES

1. Colbert, W. H. et al (Libbey-Owens-Ford Glass) U. S. Patent 2,628,927.

2. Mochel, J. M. (Corning Glass Co.) U. S. Patent 2,564,709
   Lytle, William O. (Pittsburgh Plate Glass) U. S. Patent 2,648,754

3. Coltman, J. W. (Westinghouse) Radiology 51,1948
   U. S. Patent 2,606,299
   U. S. Patent 2,681,868

4. Gomer, R, "Preparation and Some Properties of Conducting Transparent Glass", Rev. of Sci. Instr. 24, p. 993, Oct. 1953.

5. Selwyn, E. W. H., Photography in Astronomy, 1950, Eastman Kodak Co. pp. 51-61.

NOTES

1. The eye-response sensitivity of the green Q3-2657 phosphor is approximately 375 Ft. lamberts/ua/cm^2 -- of the blue 1411 it is about 73 ft. lamberts/ua/cm^2. Television picture tubes have an average sensitivity of 330 ft. lambert/ua/cm^2 but with a broad emission band to give essentially white light emission. These values are for clear-face, aluminized tubes operated with a final anode voltage of 10 KV. At 20 KV these values would be nearly 2.4 times greater owing to the doubled voltage and the lower percentage absorption of the aluminum film.

2. Rose, A, Advances in Electronics, Vol. 1, pp-131 to 166, (1948).

3. Formulated by Nate Levin, Rauland chief chemist, to have a proper quantity of slow-drying solvents so that the film will remain quite plastic during pour-off of the water.

4. The "aquadag" is electrically conducting carbon and provides a ready means of forming anode rings on glass. It also has the property of absorbing large quantities of cesium and thus completely protects the fluorescent screen from being contaminated by the hot cesium vapors (the aluminum film does not completely protect the screen from cesium). Many believe that aquadag will shorten the life of the antimony-cesium photosurface but the photo-sensitivity of tubes which were made several months before they were last tested had not changed significantly. The "aquadag" mixture as formulated by A. Schmidt of th these Laboratories (as well as the chrome oxide) is as follows:

1)	3 Tablespoons	Dixonac Graphite
2)	6 "	Aquadag (Acheson Colloids Corp.)
3)	50 ml	Kasil #1 (potassium silicate of Philidelphia Quartz Co)
4)	250 Ml	Deionized water

   The mixture is thoroughly stirred for 15 minutes and allowed to stand until free of bubbles. It will remain usable for about two weeks.

5. The chrome oxide "paint" is prepared by ball-milling 200 gms Cr_2O_3 powder with sufficient deionized water to make a thin paste for 12 hours. To about 20 gms

of the rolled mixture is added a small quantity of 15% silicate solution (15 parts Kasil #1 in 85 parts of water) while stirring until the mix becomes just fluid enough to paint onto the glass.

6. 6 mg. of aluminum is evaporated from a tungsten heater at a distance of 12.7 cm from the cathode face. Calculations from the formula $= \frac{m}{4}$ (Strong, J. Procedures in Experimental Physics, Prentice-Hall 1945, page 177) where = density = 2.7 and = distance lead to this result of 100 x 100^{-8} cm.

7. Exposure of the aluminum to U. V. to ensure complete oxidation was suggested by Dr. H. Bruining, Philips Research Labs., Eindhoven, The Netherlands.

8. For small numbers of electrodes whose dimensions are subject to change with each two or three tubes, the machining method offers the quickest solution to the problem of obtaining electrodes with precise control of their dimensions. Seamless tubing with a thin enough wall thickness (about .015") was obtained with egg-shaped cross-section after several months wait for delivery, and it had to be shaped by hand and die-gauge operations before it could be used. Spinning methods of forming the electrodes were considered but not tried. For precise, quantity production deep drawing and punch and die operations can be be used, of course.

9. The most successful method developed for forming an adherent coating of vacuum-suitable carbon or reduced phenolic resin was to brush clear insulating lacquer (Jewel Paint Co. #4593) on the inner surface of the electrode (carefully avoid touching the edges) and then heat (with RF) the electrode in a vacuum to 850°C (the deposit "burns" or evaporates (?) at higher temperatures).

10. If palladium conditioning is required, the tube is heated to 365°C in about 10 minutes time for about six minutes with argon introduced at 280°C to a few microns pressure in order to minimize the sublimation of antimony. Antimony has an appreciable vapor pressure at temperatures in excess of 310°C.

11. Polkowsky, J. J., U. S. Pat. 2,676,282, April 1954 shows the shift of, and increase of, the photoresponse of $SbCs_3$ surfaces toward longer wavelengths from its S-9 peak of 4300 A.

12. A bake to 140° to 200°C seems to inhibit the enhancement of photo-emission by the oxidized manganese indicating that absorbed oxygen which may oxidize some of the antimony as it is evaporated may be important to the process. This observation has not been well established by many experiments but is in line with the observations of Polkowsky that the ozone method of oxidation is the one which gives the best results. Of course, the manganese may not be completely oxidized to MnO or MnO_2 as is indicated by the failure to attain nearly complete transmission by the O_3 treatment, -- however, resistivity measurements show a loss of manganese conduction at this stage.

13. If the conductive surface is the iridized surface (section H) care is taken that the cathode surface does not attain a temperature of 140°. Otherwise, the higher temperature is preferred as the readings on the recorder change more rapidly and they are more easily interpreted.

14. Sensitivities of 40 ua/l have been attained a few times and these were obtained with no more than three repeats of steps 10 to 15 -- the significance of which is considered slight. Only one of these tubes was sealed off the pump in operating condition and this tube showed cesium leakage between electrodes. Phototubes in pyrex glass envelopes with no 304 SS cylinders nor mesh nor conductive film on the glass could readily be made to have 40 to 60 ua/l sensitivities.

15. Mr. Ben B. Johnstone, Ass't Chief, Physics Branch at Wright Field, explored the possibility of designing the lens as part of the fluorescent screen tube face and obtained the opinion of Dr. J. G. Baker, Harvard Observatory, that by a combination of refractive and reflective elements an F/c35 system could be designed for any particular image-object ratio. At the moment it is uncertain whether he meant that the lens system disobeyed Abbe's Law (which, however, does not consider systems in which the object, Fluorescent screen, is immersed in a medium of high refractive index) and actually has a brightness gain, or he meant that substituting an F/No = .35 into formula 4 (an approximate formula) would give the proper illumination efficiency, that is, $E_2 = E_1 \left(\frac{1}{2x.35x2}\right)^2 = E_1 \left(\frac{1}{1.4}\right)^2$ or an efficiency of 40.8% if = 0.8 could be obtained. This efficiency is approximately 10 times greater than that attainable with our present double lens system using two F/1.9 lenses.

16. Suggested by E. Turula of the Wollensak Optical Company as a solution used by others in a similar situation.

17. This 1/3 "blue" lumen was the value measured by an S-9 photocell of approximately the same area as the test pattern when placed against the 5/16" thick faceplate of the blue fluorescent screen.

OPERATING PROCEDURE FOR HIGH-SPEED SHUTTER TUBE AND ASSOCIATED EQUIPMENT

The following sequence must be followed to prevent damage to this equipment.

1. Make certain that all power switches are in OFF position before applying any line voltage.

2. Apply line voltage.

3. Turn bias supply (left bottom rack) filament and B switches ON. After 30-second time delay relay in bias supply closes, the voltmeter will indicate approximately 250 volts.

4. Turn ON the two regulated power supplies directly above the bias supply. The voltmeters will indicate approximately 260 volts.

5. Set the synchronizer panel controls as follows: Reading from left to right, "Internal" extreme clockwise, extreme counter clockwise, "90", "4.6", and "Multi".

6. Connect an oscilloscope to the input terminal of the horizontal sweep amplifier. This sweep amplifier is directly below the shaper panel, and the input terminal is on the lower terminal board and is the sixth terminal from the left in the upper row of terminals. The correct waveform at this point is shown in Fig M-6 of the final report. Should the waveform be incorrect, careful adjustment of the two regulated power supplies referred to in item 4 above will correct it.

7. Apply image tube voltages as follows:
   a. Turn ON fourth supply from bottom of left rack and adjust to 900 volts.

   b. Turn ON the focus supply directly above the supply referred to in 7a and set to 5 kv.

   c. Turn ON the Beta high voltage supply and set to 20 kv.
   <u>WARNING:</u> THIS IS A 60 CPS POWER SUPPLY AND CAN SUPPLY A DANGEROUS SHOCK!

8. Observe the waveform referred to in item 6; if correct, turn sweep power supply (bottom right rack) ON. A field of sixteen images will now be displayed on the image tube screen if an image is focused on the photocathode. The array can be made fairly symmetrical by adjusting the up, down, left and right centering and amplitude controls on the shaper panel. A readjustment of the third supply from the bottom of the left rack is necessary when the images cannot be aligned in vertical columns.

9. The image tube control grid voltage is controlled by the potentiometer mounted on the optical bench. This voltage should be adjusted to give best resolution on the screen.

10. To change to single shot operation giving a single field of sixteen frames, the synchronizer control should be changed from "Internal" to "External Trigger". Turn the blanking sweep ON, and connect the trigger terminals as shown in the attached chart. At the moment the operator is ready to record the image, he operates the trigger switch mounted near the image tube control grid potentiometer on the optical bench. The trigger can be obtained from any source supplying a sharp pulse of at least 30 volts peak. For single frame, single shot operation, the "Multi-Single" switch on the synchronizer is changed to "Single", and the sweep amplifier power supply is turned OFF.

11. Shut down the equipment in accordance with the following procedure.

    a. Turn OFF sweep supply (bottom right rack).

    b. Turn OFF all supplies in the left rack starting at the top.

    c. Remove line voltage

    NOTE: The shutter pulse generator is not provided with a power switch, and therefore, its filaments and pilot light come on when the line voltage is applied to the rack.

VOLTAGE MEASUREMENTS

DESCRIPTION OF CHASSIS Sweep Amplifier SCHEMATIC NO. B1219

ITEM	TUBE	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7	PIN 8	PIN 9	TUBE CAP
V1	6BQ7	175 V.	-12 V.	1.2 V†	6.3 VAC	6.3 VAC	175 V†	-12 V.	1.2 V.	0 V.	
V2	6CL6	0 V.	0.5V	70 V.	6.3 VAC	6.3 VAC	70 V.	0 V.	70 V.	0.5 V.	
V3	6CL6	0 V.	0.5 V.	70 V.	6.3 VAC	6.3 VAC	70 V.	0 V.	70 V.	0.5 V.	
V4	6BQ7	280 V.	-39 V	-35 V.	6.3 VAC	6.3 VAC	280 V.	-39 V.	-35 V.	0 V.	
V5	6BG6G	0 V.	6.3 VAC	.55 †	0 V.	-35 V.	0 V.	6.3 VAC	270 V.		380 V.
V6	6BG6G	0 V.	6.3 VAC	.55 †	0 V.	-35 V.	0 V.	6.3 VAC	270 V.		380 V.
V7	6BG6G	0 V.	6.3 VAC	.55 †	0 V.	-35 V.	0 V.	6.3 VAC	270 V.		380 V.
V8	6BG6G	0 V.	6.3 VAC	.55 †	0 V.	-35 V.	0 V.	6.3 VAC	270 V.		380 V.

1 - These voltages measured under the special operating conditions described above.
2 - DC voltage measurements are at 20,000 ohms per volt; AC voltage measured at 1,000 ohms.
3 - Pin numbers are counted in a clockwise direction on bottom of socket.
4 - Measured values are from socket pins to chassis ground except for heaters.
5 - Heaters measured to opposite side of heater.
6 - Line voltage maintained at 117 volts for voltage reading.
7 - Unless otherwise indicated voltages are DC.

†- These values for vertical amplifier. Values for horizontal amplifier about 0.4 V. lower

VOLTAGE MEASUREMENTS

DESCRIPTION OF CHASSIS SYNCHRONIZER SCHEMATIC NO. C1037

ITEM	TUBE	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7	PIN 8	PIN 9	TUBE CAP
V1	6AU6	-20V.	10 V.	6.3 VAC	6.3 VAC	230 V.	160 V.	10 V.			
V2	6BQ7	70 V.	-1.2 V.	0 V.	6.3 VAC	6.3 VAC	200 V.	-60 V.	0 V.	0 V.	
V3	6BQ7	240 V.	0 V.	10.5 V.	6.3 VAC	6.3 VAC	235 V.	-80 V.	0 V.	0 V.	
V4	6BQ7	24 V.	-2.5 V.	0 V.	6.3 VAC	6.3 VAC	230 V.	24 V.	140 V.	0 V.	
V5	6BQ7	240 V.	42 V.	46 V.	6.3 VAC	6.3 VAC	74 V.	-10 V.	0 V.	0 V.	
V6	UNUSED	80 V.	0 V.	6.3 VAC	6.3 VAC	0 V.	0 V.	0 V.			
V7	6BQ7	190 V.	-54 V.	0 V.	6.3 VAC	6.3 VAC	82 V.	-2.8 V.	0 V.	0 V.	
V8	6BQ7	240 V.	30 V	34 V.	6.3 VAC	6.3 VAC	160 V.	28 V.	30 V.	0 V.	
V9	6CL6	31 V.	30 V.	135 V.	6.3 VAC	6.3 VAC	120 V.	31 V.	135 V.	30 V.	
V10	6CL6	31 V.	-41 V.	150 V.	6.3 VAC	6.3 VAC	235 V.	31 V.	150 V.	-41 V.	
V11	6AG7	0 V.	6.3 VAC	0 V.	-24 V.	0.35 V.	240 V.	6.3 VAC	240 V.		

1 - These Voltage measured under the special operating conditions described above.
2 - DC voltage measurements are at 20,000 ohms per volt; AC voltage measured at 1,000 ohms.
3 - Pin numbers are counted in a clockwise direction on bottom of socket.
4 - Measured values are from socket pins to chassis ground except for heaters.
5 - Heaters measured to opposite side of heater.
6 - Line voltage maintained at 117 volts for voltage reading.
7 - Unless otherwise indicated boltages are DC.

VOLTAGE MEASUREMENTS

DESCRIPTION OF CHASSIS Shaper SCHEMATIC NO. C1357

ITEM	TUBE	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7	PIN 8	PIN 9	TUBE CAP
V1	6CL6	19 V.	-0.2 V.	230 V.	6.3 VAC	6.3 VAC	230 V.	19 V.	230 V	-0.2 V.	
V2	6CL6	0 V.	-15 V.	70 V.	6.3 VAC	6.3 VAC	200 V.	0 V.	70 V.	-15 V.	
V3	6CL6	0 V.	0 V.	70 V.	6.3 VAC	6.3 VAC	33 V.	0 V.	70 V.	0 V.	
V4	6AL5	210 V.	200 V.	6.3 VAC	6.3 VAC	210 V.	0 V.	33 V.			
V5	6CL6	0 V.	-14 V.	75 V.	6.3 VAC	6.3 VAC	200 V.	0 V.	75 V.	-14 V.	
V6	6CL6	0 V.	0.2 V.	75 V.	6.3 VAC	6.3 VAC	35 V.	0 V.	75 V.	0.2 V.	
V7	6AL5	220 V.	200 V.	6.3 VAC	6.3 VAC	220 V.	0 V.	35 V.			
V8	6CL6	0 V.	-15 V.	70 V.	6.3 VAC	6.3 VAC	200 V.	0 V.	70 V.	-15 V.	
V9	6CL6	0 V.	0.15 V.	70 V.	6.3 VAC	6.3 VAC	34 V.	0 V.	70 V.	0.15 V.	
V10	6AL5	220 V.	200 V.	6.3 VAC	6.3 VAC	220 V.	0 V.	34 V.			
V11	6CL6	0 V.	-15 V.	77 V.	6.3 VAC	6.3 VAC	200 V.	0 V.	77 V.	-15 V.	
V12	6CL6	0 V.	0.1 V.	77 V.	6.3 VAC	6.3 VAC	37 V.	0 V.	77 V.	0.1 V.	
V13	6AL5	220 V.	200 V.	6.3 VAC	6.3 VAC	220 V.	0 V.	37 V.			
V14	6CL6	0 V.	-5.8 V.	128 V.	6.3 VAC	6.3 VAC	98 V.	0 V.	128 V.	-5.8 V.	
V15	6CL6	0 V.	-3.2 V.	128 V.	6.3 VAC	6.3 VAC	74 V.	0 V.	128 V.	-3.2 V.	
V16	6CL6	0 V.	-2.6 V.	115 V.	6.3 VAC	6.3 VAC	66 V.	0 V.	115 V.	-2.6 V.	
V17	6CL6	0 V.	-2.3 V.	115 V.	6.3 VAC	6.3 VAC	77 V.	0 V.	115 V.	-2.3 V.	
V18	6CL6	0 V.	- 7 V.	115 V.	6.3 VAC	6.3 VAC	50 V.	0 V.	115 V.	- 7 V.	
V19	6BQ7	240 V.	-17 V.	- 6 V.	6.3 VAC	6.3 VAC	0 V.	0 V.	-0.1 V.	0 V.	
V20	6CL6	0 V.	-3.2 V.	135 V.	6.3 VAC	6.3 VAC	75 V.	0 V.	135 V.	-3.2 V.	
V21	6BQ7	240 V.	-12 V.	-3.7 V.	6.3 VAC	6.3 VAC	240 V.	-20 V.	-3.7 V.	0 V.	
V22	6BQ7	240 V.	-20 V.	- 5 V.	6.3 VAC	6.3 VAC	240 V.	-12 V.	- 4 V.	0 V.	
V23	6AL5	165 V.	0 V.	6.3 VAC	6.3 VAC	0 V.	0 V.	33 V.			

1 - These voltages measured under the special operating conditions described above.
2 - DC voltage measurements are at 20,000 ohms per volt; AC voltage measured at 1,000 ohms.
3 - Pin numbers are counted in a clockwise direction on bottom of socket.
4 - Measured values are from socket pins to chassis ground except for heaters.
5 - Heaters measured to opposite side of heater.
6 - Line voltage maintained at 117 Volts for voltage reading.
7 - Unless otherwise indicated voltages are DC.

VOLTAGE MEASUREMENTS

DESCRIPTION OF CHASSIS Shutter Pulse Generator — SCHEMATIC NO. C1229

ITEM	TUBE	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7	PIN 8	PIN 9	TUBE CAP
V1	6CL6	-220 V.	-240 V.	0 V.	6.3 VAC	6.3 VAC	-15 V.	-220 V.	0 V.	-240 V.	
V2	6CL6	-240 V.	-245 V.	-96 V.	6.3 VAC	6.3 VAC	- 6 V.	-240 V.	-96 V.	-240 V.	
V3	6CL6	-240 V.	-245 V.	-96 V.	6.3 VAC	6.3 VAC	-85 V.	-240 V.	-96 V.	-240 V.	
V4	6CL6	-240 V.	-280 V.	-122 V.	6.3 VAC	6.3 VAC	- 4 V.	-240 V.	-122 V.	-280V.	
V5	6CL6	-230 V.	-230 V.	-122 V.	6.3 VAC	6.3 VAC	-127 V.	-230 V.	-122 V.	-230 V.	
V6	6CL6	-230 V.	-235 V.	-60 V.	6.3 VAC	6.3 VAC	-116 V.	-230 V.	-60 V.	-235 V.	
V7	6CL6	-230 V.	-250 V.	-60 V.	6.3 VAC	6.3 VAC	-97 V.	-230 V.	-60 V.	-250 V.	
V8	6CD6G	0 V.	6.3 VAC	-92 V.	-116 V.	-116 V.	0 V.	6.3 VAC	-18 V.		- 1 V.
V9	6CD6G	0 V.	6.3 VAC	-92 V.	- 97 V.	- 97 V.	0 V.	6.3 VAC	-18 V.		-47 V.
V10	6BG6G	0 V.	6.3 VAC	-220 V.	0 V.	-230 V.	-240 V.	6.3 VAC	-97 V.		-97 V.
V11	OD3	-190 V.	-390 V.	0 V.	0 V.	-240 V.	-240 V.	0 V.	0 V.		

1 - These voltages measured under the special operating conditions described above.
2 - DC voltage measurements are at 20,000 ohms per volt; AC voltage measured at 1,000 ohms.
3 - Pin numbers are counted in a clockwise direction on bottom of socket.
4 - Measured values are from socket pins to chassis ground except for heaters.
5 - Heaters measured to opposite side of heater.
6 - Line voltage maintained at 117 volts for voltage reading.
7 - Unless otherwise indicated voltages are DC.

V O L T A G E   M E A S U R E M E N T S

DESCRIPTION OF CHASSIS Deflection Blanking SCHEMATIC NO. B1554

ITEM	TUBE	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7	PIN 8	PIN 9	TUBE CAP
V1	6AU6	0 V.	7 V.	6.3 VAC.	6.3 VAC	145 V.	100 V.	7 V.			
V2	2D21	-8 V.	0.2 V.	6.3 VAC	6.3 VAC	0.2 V.	18 V.	0 V.			
V3	6BQ7	135 V.	-44 V.	0 V.	6.3 VAC	6.3 VAC	32 V.	-0.3 V.	0 V.	0 V.	
V4	6BQ6G	135 V.	6.3 VAC	0 V.	80 V.	26 V.	0 V.	6.3 VAC	26 V.		250 V.
V5	5Y3GT	0 V.	5 VAC*	0 V.	450 VAC	0 V.	450 VAC	0 VAC	5 VAC*		
V6	6X5GT	0 V.	6.3 VAC	-500 V.	0 V.	-500 V.	0 V.	6.3 VAC	450 VAC		
V7	OD3	0 V.	0 V.	0 V.	0 V.	145 V.	250 V.	0 V.	250 V.		
V8	OD3	0 V.	-148 V.	0 V.	0 V.	0 V.	0 V.	0 V.	0 V.		

1 - These voltages measured under the special operating conditions described above.
2 - DC voltage measurements are at 20,000 ohms per volt; AC voltage measured at 1,000 ohms.
3 - Pin numbers are counted in a clockwise direction on bottom of socket.
4 - Measured values are from socket pins to chassis ground except for heaters.
5 - Heaters measured to opposite side of heater.
6 - Line voltage maintained at 117 volts for voltage reading.
7 - Unless otherwise indicated voltages are DC.

* - These points are at +320 v. DC.

VOLTAGE MEASUREMENTS

DESCRIPTION OF CHASSIS Regulated High Voltage Supply SCHEMATIC NO. B1060

ITEM	TUBE	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7	PIN 8	PIN 9	TUBE CAP
V1	1X2A	DO NOT MEASURE									
V2	12AT7	76 V.	-3.6 V.	0 V.	6.3 VAC	6.3 VAC	150 V.	-27 V.	0 V.	6.3 VAC	
V3	6AU6	-3.5 V.	0 V.	6.3 VAC	6.3 VAC	160 V.	90 V.	0 V.			
V4	0A2	0 V.	-150 V.	0 V.	-150 V.	0 V.	0 V.	-150 V.			
V5	6AU6	-9.5 V.	0 V.	6.3 VAC	6.3 VAC	105 V.	54 V.	0 V.			
V6	6BQ6	0 V.	6.3 VAC	-50 V.	170 V.	-49 V.	0 V.	6.3 VAC	0 V.		350 V.

1 - These voltages measured under the special operating conditions described above.
2 - DC voltage measurements are at 20,000 ohms per volt; AC voltage measured at 1,000 ohms.
3 - Pin numbers are counted in a clockwise direction on bottom of socket.
4 - Measured values are from socket pins to chassis ground except for heaters.
5 - Heaters measured to opposite side of heater.
6 - Line voltage maintained at 117 volts for voltage reading.
7 - Unless otherwise indicated voltages are DC.

VOLTAGE MEASUREMENTS

DESCRIPTION OF CHASSIS Flash Lamp Pulser SCHEMATIC NO. EX-21339

ITEM	TUBE	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7	PIN 8	PIN 9	TUBE CAP
V1	6BQ7	230 V.	-19 V.	0 V.	6.3 VAC	6.3 VAC	190 V.	-6 V.	0 V.	0 V.	
V2	6BQ7	230 V.	-52 V.	0 V.	6.3 VAC	6.3 VAC	45 V.	-0.3 V.	0 V.	0 V.	
V3	6BL7	60 V.	230 V.	70 V.	0 V.	0 V.	0 V.	6.3 VAC	6.3 VAC		
V4	4C35*	-0.3 V.	6.3 VAC	6.3 VAC	0 V.						DO NOT MEASURE

1 - These voltages measured under the special operating conditions described above.
2 - DC voltage measurements are at 20,000 ohms per volt; AC voltage measured at 1,000 ohms.
3 - Pin numbers are counted in a clockwise direction on bottom of socket.
4 - Measured values are from socket pins to chassis ground except for heaters.
5 - Heaters measured to opposite side of heater.
6 - Line voltage maintained at 117 volts for voltage reading.
7 - Unless otherwise indicated voltages are DC.

* - Measurement made with high voltage off.

VOLTAGE MEASUREMENTS

DESCRIPTION OF CHASSIS Sweep Power Supply SCHEMATIC NO. C1308

ITEM	TUBE	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7	PIN 8	PIN 9	TUBE CAP
V1	5R4GY	0 V.	5 VAC	390 V.	550 VAC	0 V.	550 VAC	0 V.	5 VAC.		
V2	5R4GY	0 V.	5 VAC	390 V.	550 VAC	0 V.	550 VAC	0 V.	5 VAC		
V3	OC3	0 V.	0 V.	380 V.	270 V.	105 V.	270 V.	380 V.	0 V.		
V4	12 AT7	150 V.	102 V.	105 V.	6.3 VAC	6.3 VAC	250 V.	145 V.	150 V.	6.3 VAC	
V5	6B4G	0 V.	6.3 VAC*	380 V.	250 V.	250 V.	0 V.	6.3 VAC	0 V.		
V6	6B4G	0 V.	6.3 VAC*	380 V.	250 V.	250 V.	0 V.	6.3 VAC	0 V.		
V7	6B4G	0 V.	6.3 VAC*	380 V.	250 V.	250 V.	0 V.	6.3 VAC	0 V.		

1 - These voltages measured under the special operating conditions described above.
2 - DC voltage measurements are at 20,000 ohms per volt; AC voltage measured at 1,000 ohms.
3 - Pin numbers are counted in a clockwise direction on bottom socket.
4 - Measured values are from socket pins to chassis ground except for heaters.
5 - Heaters measured to opposite side of heater.
6 - Line voltage maintained at 117 Volts for voltage reading.
7 - Unless otherwise indicated voltages are DC.

* - Pin 2 tied to +270 V. DC. regulated output.

VOLTAGE MEASUREMENTS

DESCRIPTION OF CHASSIS Regulated Power Supply SCHEMATIC NO. C1235

ITEM	TUBE	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7	PIN 8	PIN 9	TUBE CAP
V1	5R4GY	0 V.	5 VAC*	0 V.	550 VAC	0 V.	550 VAC.	0 V.	5 VAC*		
V2	5R4GY	0 V.	5 VAC*	0 V.	550 VAC	0 V.	550 VAC	0 V.	5 VAC*		
V3	6B4G	0 V.	6.3 VAC†	400 V.	220 V.	220 V.	0 V.	6.3 VAC†	0 V.		
V4	6B4G	0 V.	6.3 VAC†	400 V.	220 V.	220 V.	0 V.	6.3 VAC†	0 V.		
V5	6B4G	0 V.	6.3 VAC†	400 V.	220 V.	220 V.	0 V.	6.3 VAC†	0 V.		
V6	6B4G	0 V.	6.3 VAC†	400 V.	220 V.	220 V.	0 V.	6.3 VAC†	0 V.		
V7	6B4G	0 V.	6.3 VAC†	400 V.	220 V.	220 V.	0 V.	6.3 VAC†	0 V.		
V8	6SL7GT	102 V.	220 V.	105 V.	102 V.	220 V.	105 V.	6.3 VAC#	6.3 VAC#		
V9	0C3	0 V.	0 V.	430 V.	250 V.	105 V.	0 V.	430 V.	250 V.		
V10	6SL7GT	70 V.	102 V.	72 V.	70 V.	250 V.	72 V.	6.3 VAC#	6.3 VAC#		

1 - These voltages measured under the special operating conditions described above.
2 - DC voltage measurements are at 20,000 ohms per volt; AC voltage measured at 1,000 ohms.
3 - Pin numbers are counted in a clockwise direction on bottom of socket.
4 - Measured values are from socket pins to chassis ground except for heaters.
5 - Heaters measured to opposite side of heater.
6 - Line voltage maintained at 117 volts for voltage reading.
7 - Unless otherwise indicated voltages are DC.
* - At +430 volts DC.
† - At +250 volts DC.
# - At +105 volts DC.

VOLTAGE MEASUREMENTS

DESCRIPTION OF CHASSIS 1200 V. Power Supply SCHEMATIC NO. B1224

ITEM	TUBE	PIN 1	PIN 2	PIN 3	PIN 4	PIN 5	PIN 6	PIN 7	PIN 8	PIN 9	TUBE CAP
V1	5Y3GT	0 V.	5 VAC*	0 V.	325 VAC	0 V.	325 VAC	0 V.	5 VAC*		
V2	6BL7	112 V.	320 V.	134 V.	112 V.	320 V.	134 V.	6.3 VAC*	6.3 VAC#		
V3	6AU6	101 V.	105 V.	6.3 VAC#	6.3 VAC#	150 V.	260 V.	105 V.			
V4	OC3	0 V.	0 V.	0 V.	0 V.	105 V.	0 V.	0 V.	0 V.		
V5	6AQ5	-7 V.	0 V.	6.3 VAC#	6.3 VAC#	132 V.	65 V.	-7 V.			
V6	1 x 2	1.25VAC†	1.25VAC†	1.25VAC†	1.25VAC†	1.25VAC†	1.25VAC†	1.25VAC†	1.25VAC†	1.25VAC†	DO NOT MEASURE

1 - These voltages measured under the special operating conditions described above.
2 - DC voltage measurements are at 20,000 ohms per volt; AC voltage measured at 1,000 ohms.
3 - Pin numbers are counted in a clockwise direction on bottom of socket.
4 - Measured values are from socket pins to chassis ground except for heaters.
5 - Heaters measured to opposite side of heater.
6 - Line voltage maintained at 117 volts for voltage reading.
7 - Unless otherwise indicated voltages are DC.
* - At 340 volts DC.
† - At 700 volts DC. (Pins 1-9 are heaters - check book value and records in spaces above.)
\# - At 68 volts DC.

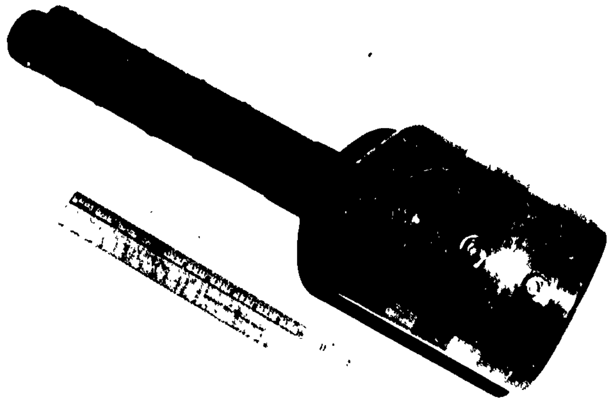


Figure 1. Shutter tube type 1 with 6-1/4 inch screen.

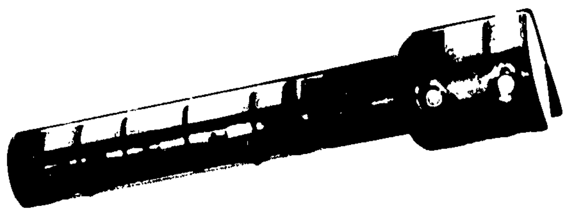


Figure 2. Shutter tube. Tube x-1001: photocathode - 1-1/8 inch diameter in 2-inch tubing; Fluorescent screen - 3-1/4 inch diameter; Sensitivity - 30 uA/lu to 2870° light.

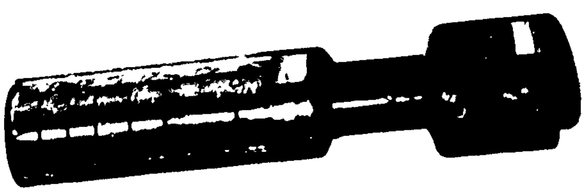


Figure 3. Shutter tube. Tube 2-7-55: Photocathode - 1-3/4 inch diameter in 3-inch diameter tubing; Fluorescent screen - 4 inch diameter; Sensitivity - 27 uA/lu to 2870° light.

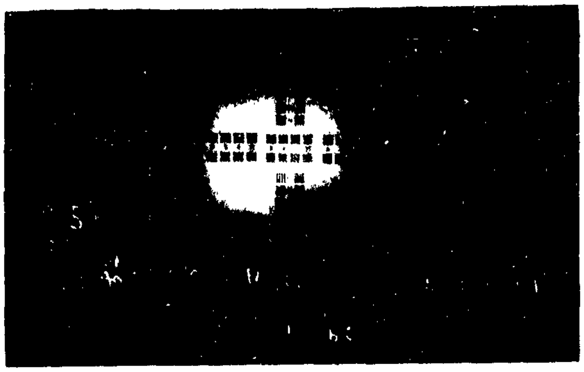


Figure 4. Tube 8-12-54. Slide projector continuously illuminating photocathode. Fluorescent screen image continuous. Camera magnification - 1.1. Royal Pan film - 1/400 sec. exposure. Maximum resolution on film - 5 lines/mm.

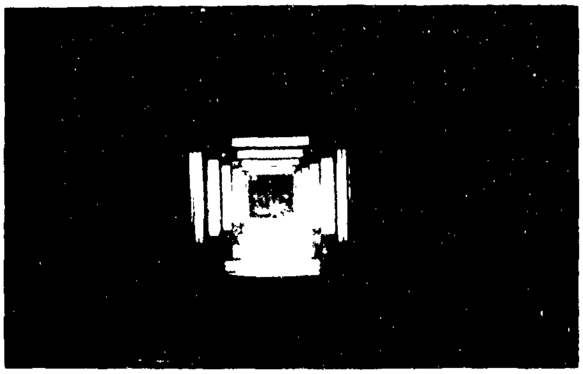


Figure 5. Tube X-1001. Slide projector continuously illuminating photocathode. Fluorescent screen image continuous. Size of fluorescent image - .8 cm. Resolution on film - 12.5 lines/mm. (Picture was taken with the photocathode at -200 volts for least astigmatism.)

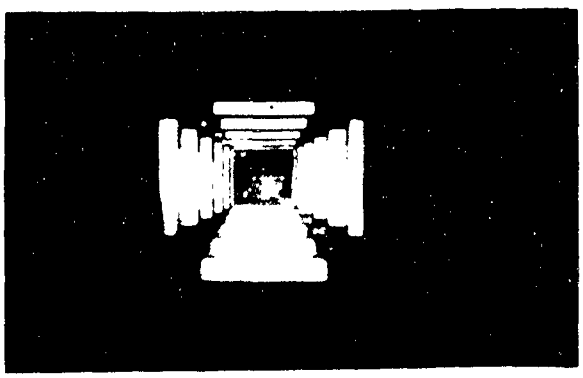


Figure 6. Tube X-1001. Same conditions as Figure 5, except cathode at -45 volts (normal operating condition for pulsed operation). Resolution same, but some what more astigmatism as Figure 5.

Figure 7. Tube 2-7-55. Slide projector continuously illuminating photocathode. Continuous pulsing at maximum rate. Size of image on photosurface - 1.5 x 1.5 cm. Size of fluorescent image - 1 cm. Camera magnification - 3.7:1. Resolution on film - 12 lines/mm.

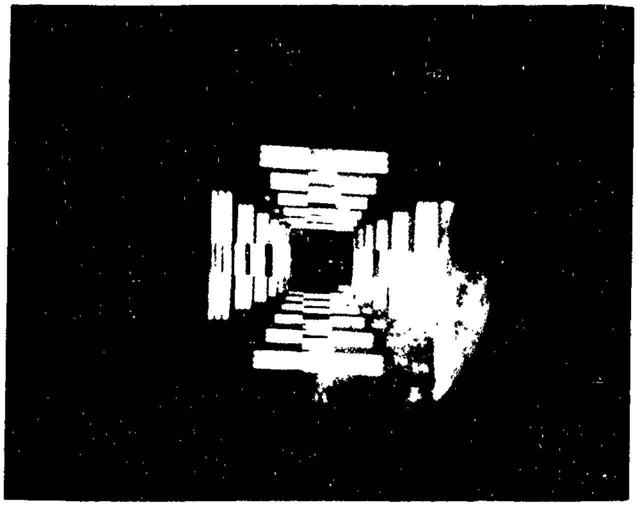


Figure 8. Tube 2-7-55. Test pattern illuminated by continuous incandescent light. Reflected image projected on the photocathode. Size of image on photocathode - 1.5 x 1.5 cm. Fluorescent image continuous. Size of fluorescent image - .9cm. Resolution on tube - 15 lines/mm as recorded on film. Resolution on tube - 16 lines/mm as seen by observer. Camera magnification 4.1:1.

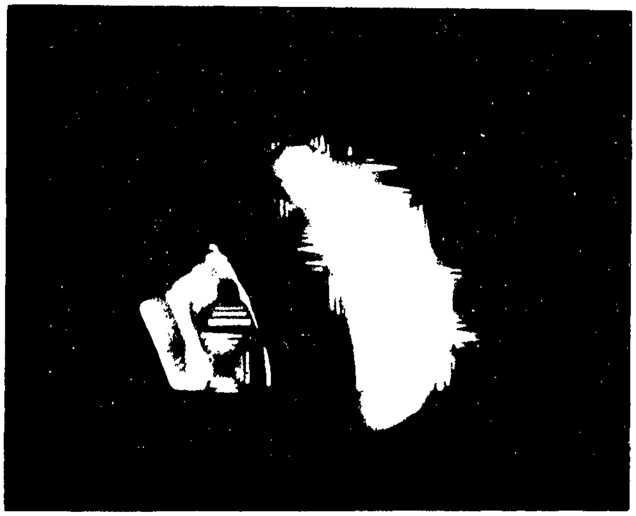


Figure 9. Tube 2-7-55. Continuous projected image onto photocathode. Single shot of 16 frames, 1 usec pulse duration, 4.6 usec frame period. Resolution on film 8 lines/mm, density of negative approximately 0.5. Camera magnification 1:1. The minimum illumination required for usec exposure measured from the illumination levels necessary for this picture was 500 ft. candles with camera lens of f 3.8.

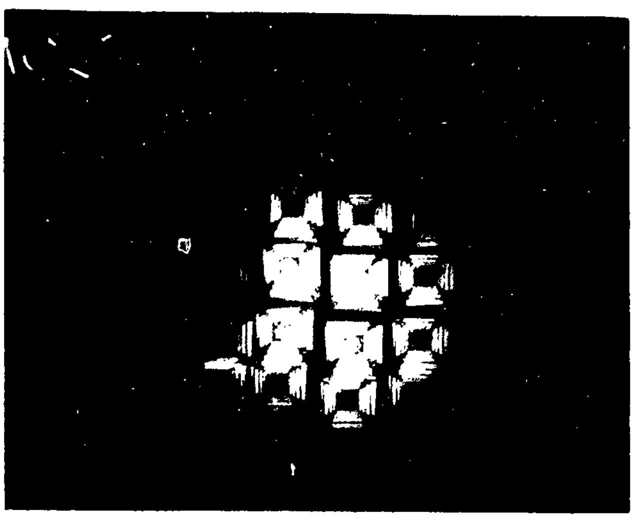


Figure 10. Tube X-1001. Pulse of light from "Kemlite" lamp special #SP72 working at 36 w. sec. input. Pulse duration 75 usec. Reflected ilumination from test pattern. Single shot picture - 16 frame 4.5 usec. Frame period - 0.5 usec pulse duration. Size of each frame image on fluorescent screen 0.9 cm. Double Wollensak F 1.9 lens back to back, magnification 1:1. Resolution on Film 8 lines/mm maximum.

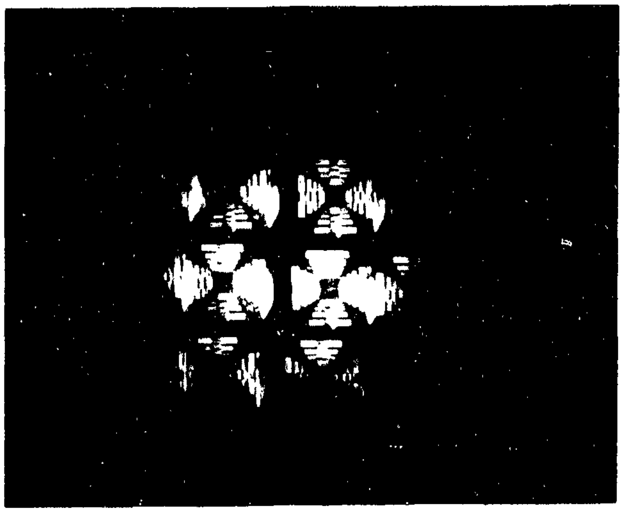


Figure 11. Tube 2-7-55. Single-shot - same conditions as Figure 10 except pulsed duration of shutter tube - .9 usec. (The edge illumination falls off because of insufficient coverage by the lens.)

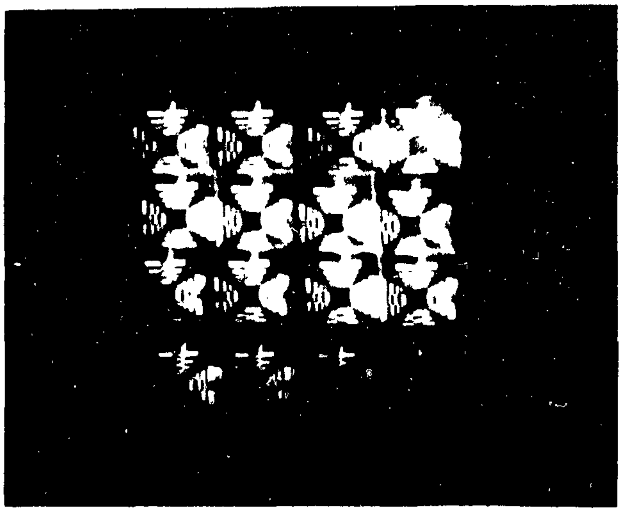


Figure 12. Tube 2-7-55. Single-shot - same conditions as Figure 10 except pulse duration 3 usec. Resolution on film 8-10 lines/mm. (The shorter exposure for first few frames is a result of too short flash duration to cover full 16 frames).

Figure 13. Tube 2-7-55. Single-shot - conditions same as Figure 11 except pulse duration 0.4 usec frame period 10 usec. Resolution on film 8 lines/mm.

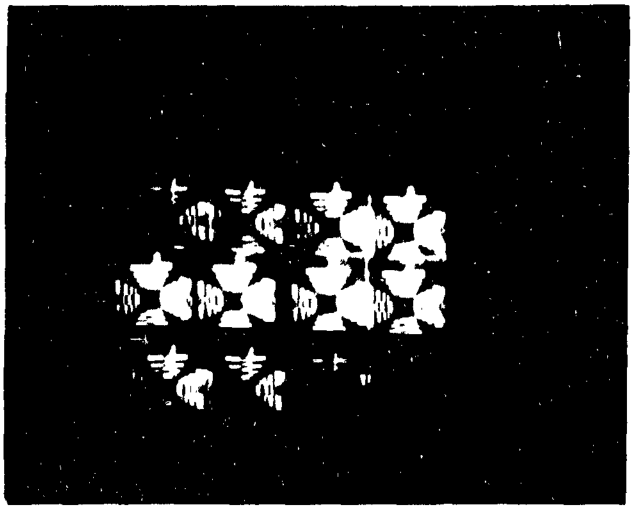


Figure 14. Tube 2-7-55. Single-shot - conditions same as Figure 13 except pulse duration 3 usec. Resolution 5 lines/mm.

Figure 15. Tube 2-7-55. Pulse of light from "Kemlite" lamp SP72. Single frame 0.3 usec. pulse duration. Resolution on film 10/lines mm.

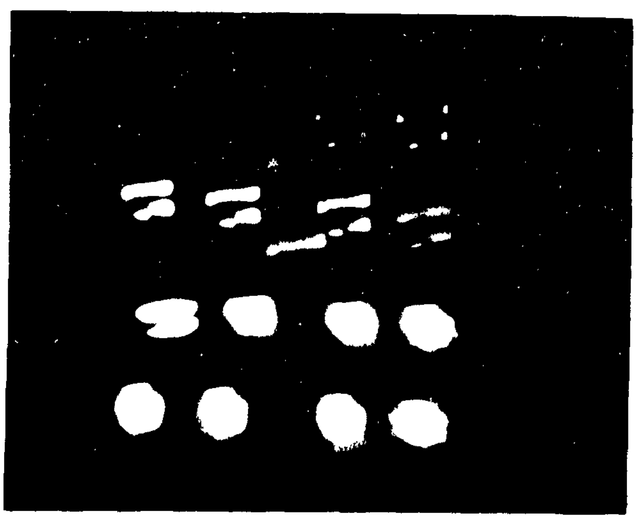


Figure 16. Tube 2-7-55. 16 frames showing build-up of arc discharge in "Kemlite" lamp SP72 viewed directly. Each frame exposed 0.3 usec, frames spaced 2 usec.

Figure 17. Recording with shutter tube showing quality of picture with 10-12 lines/mm resolution on the screen.

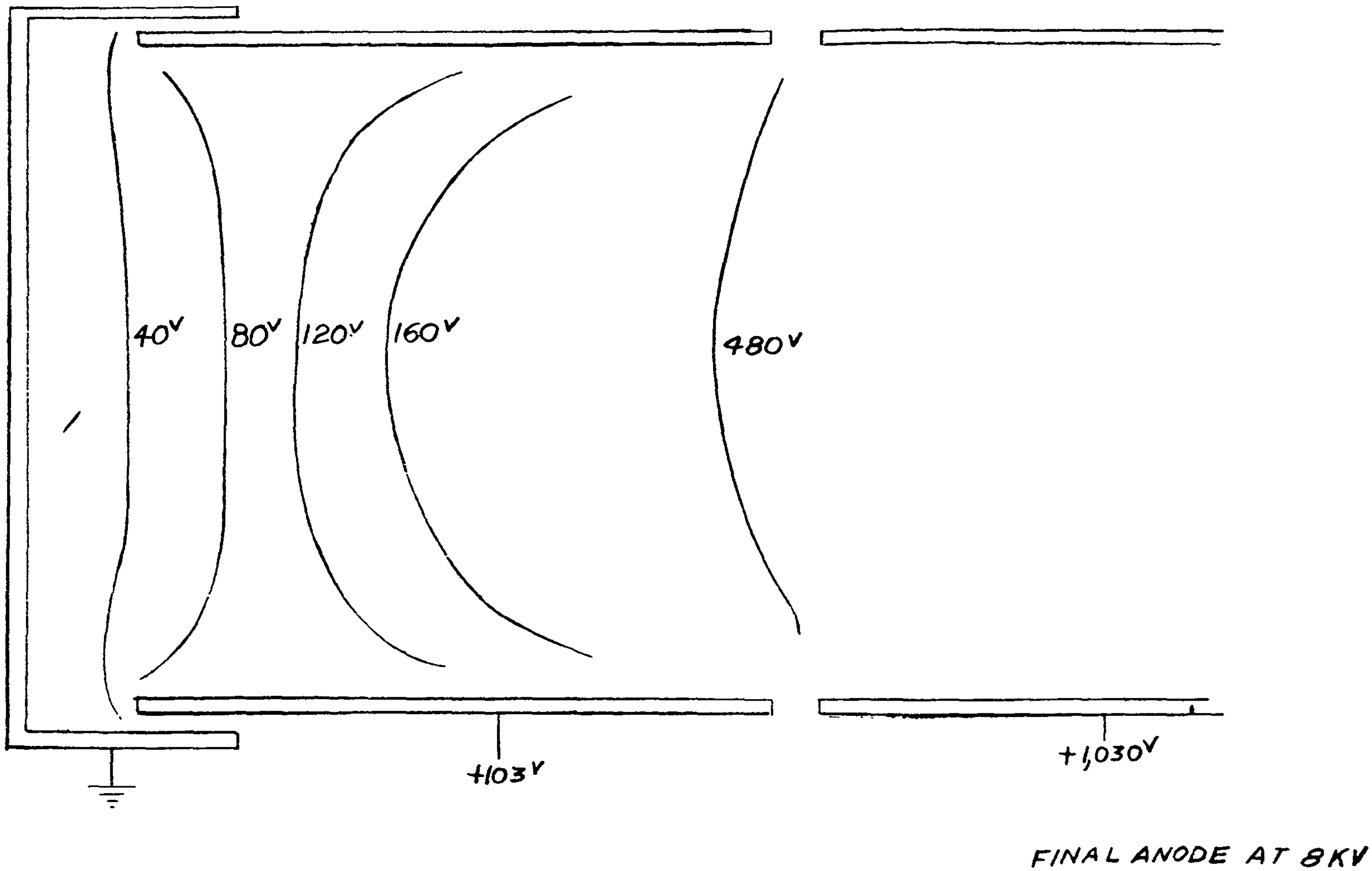
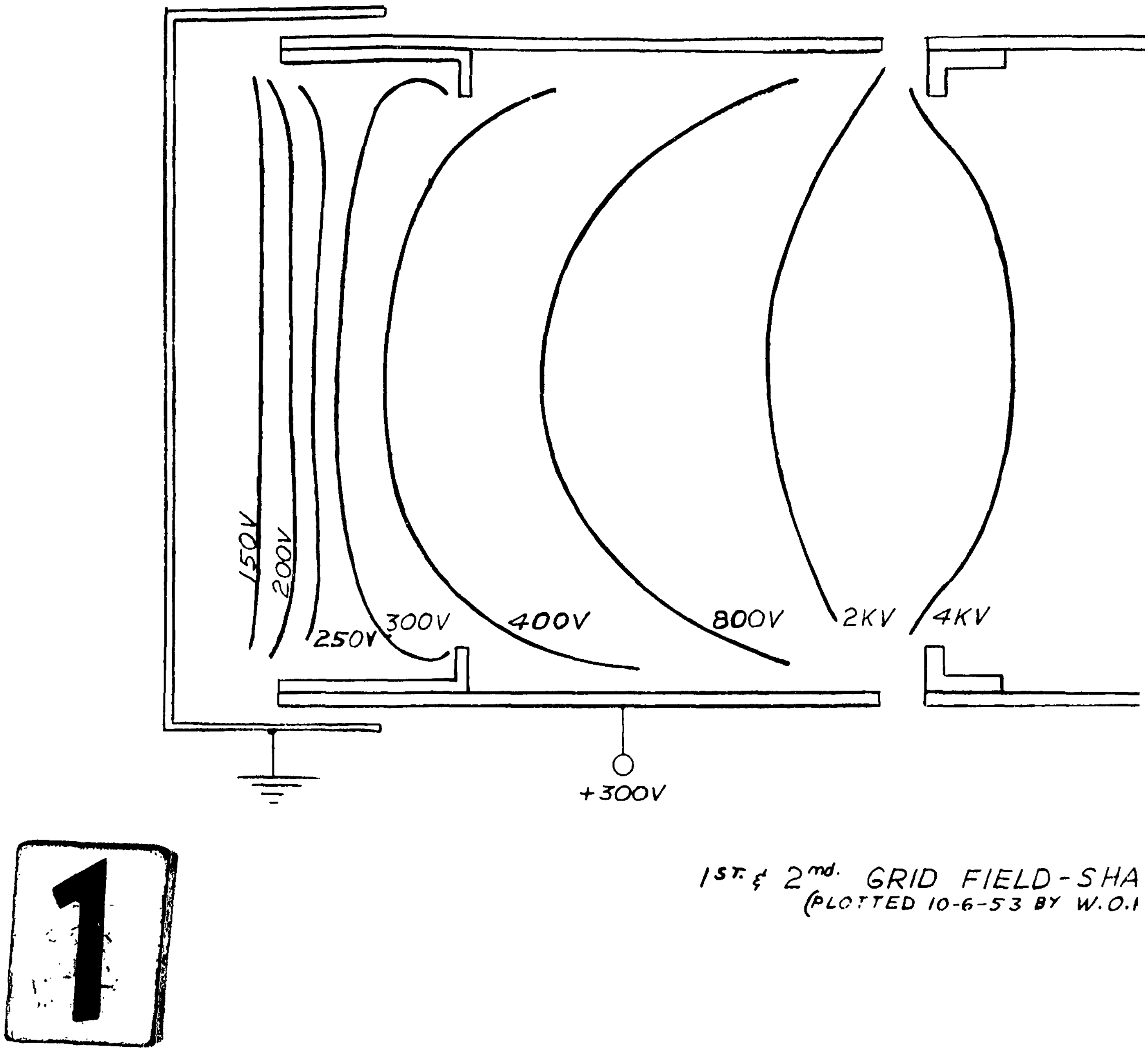
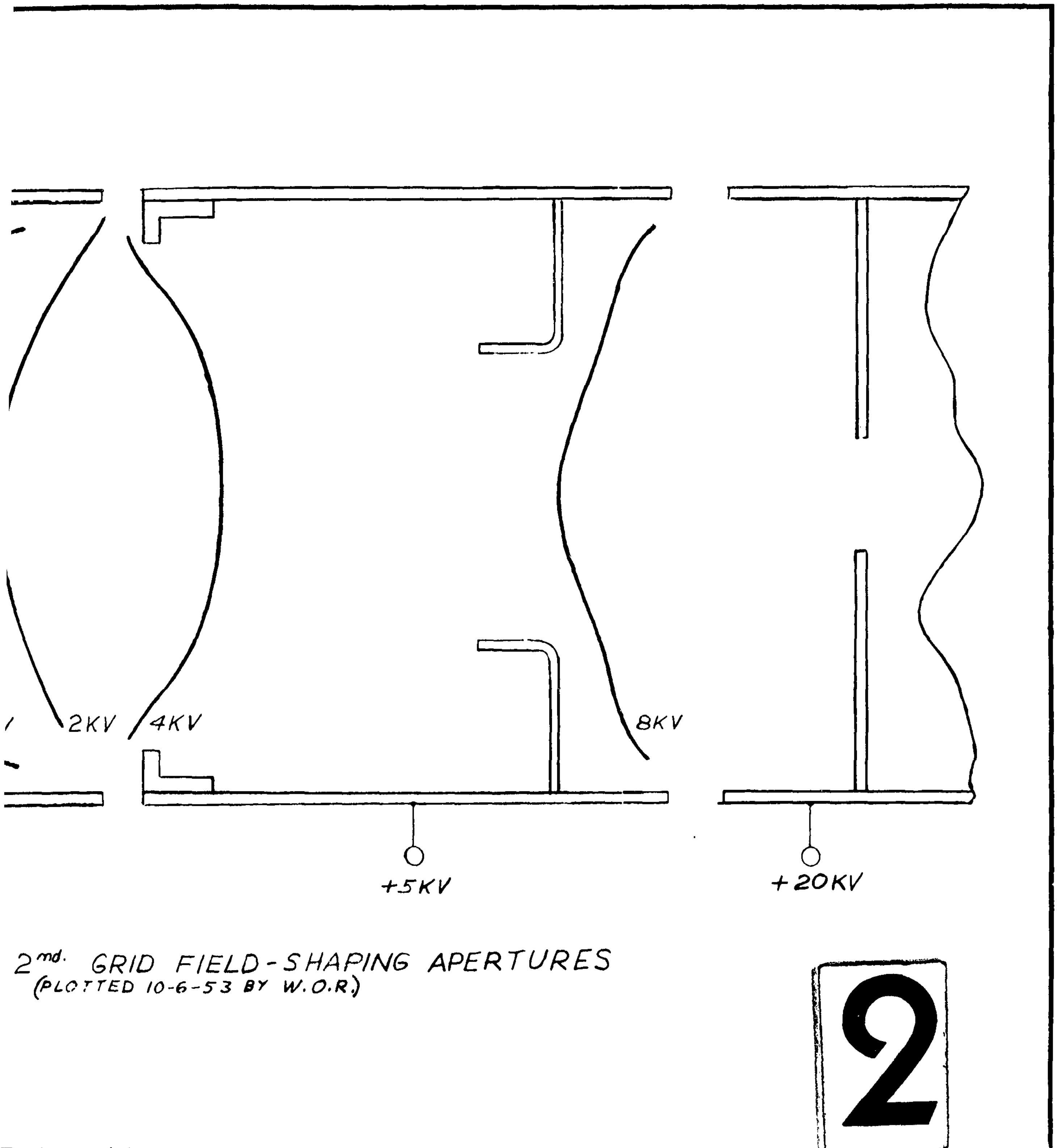


Figure 18. Equipotential plots of electrode configurations.



1^{ST} & 2^{nd} GRID FIELD-SHA
(PLOTTED 10-6-53 BY W.O.I

Figure 19. Equipotential plots of electrode c



Equipotential plots of electrode configurations.

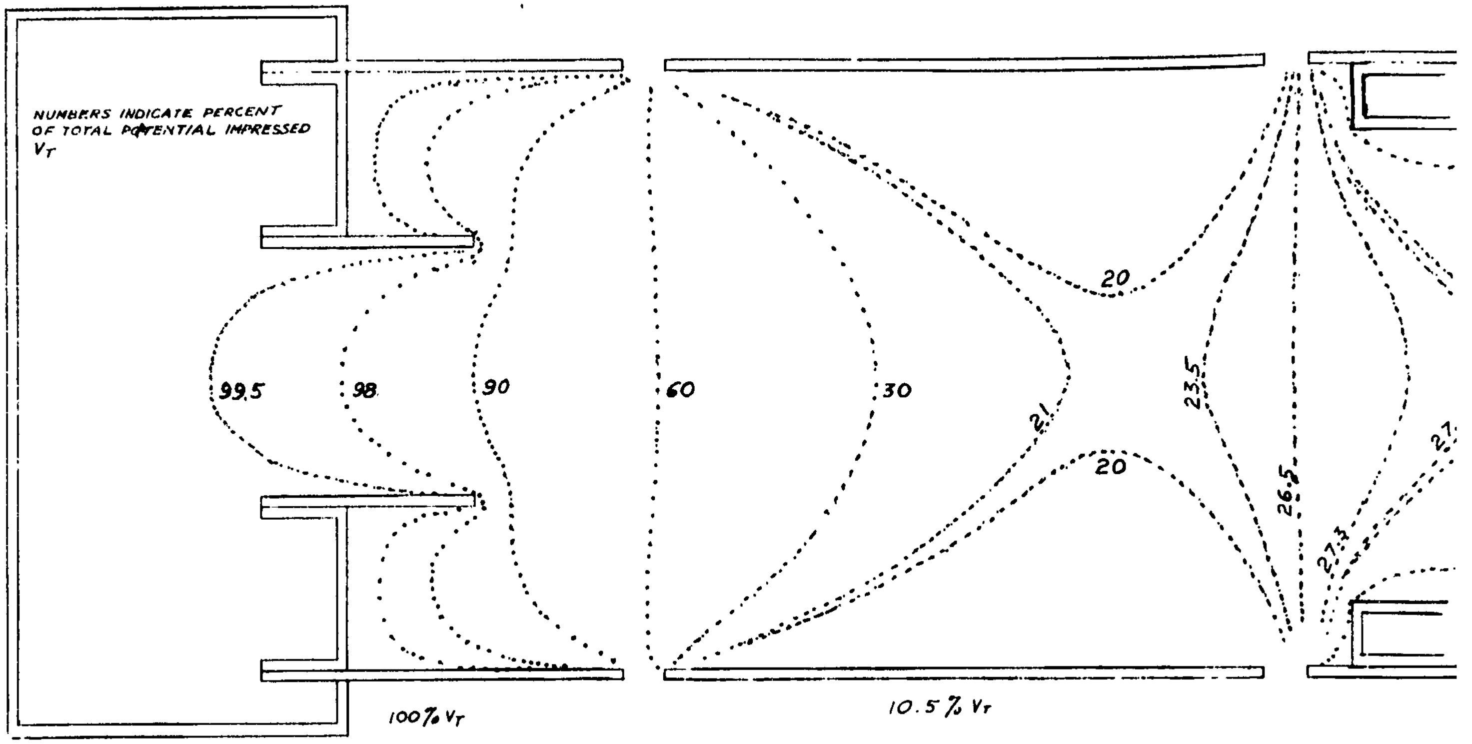
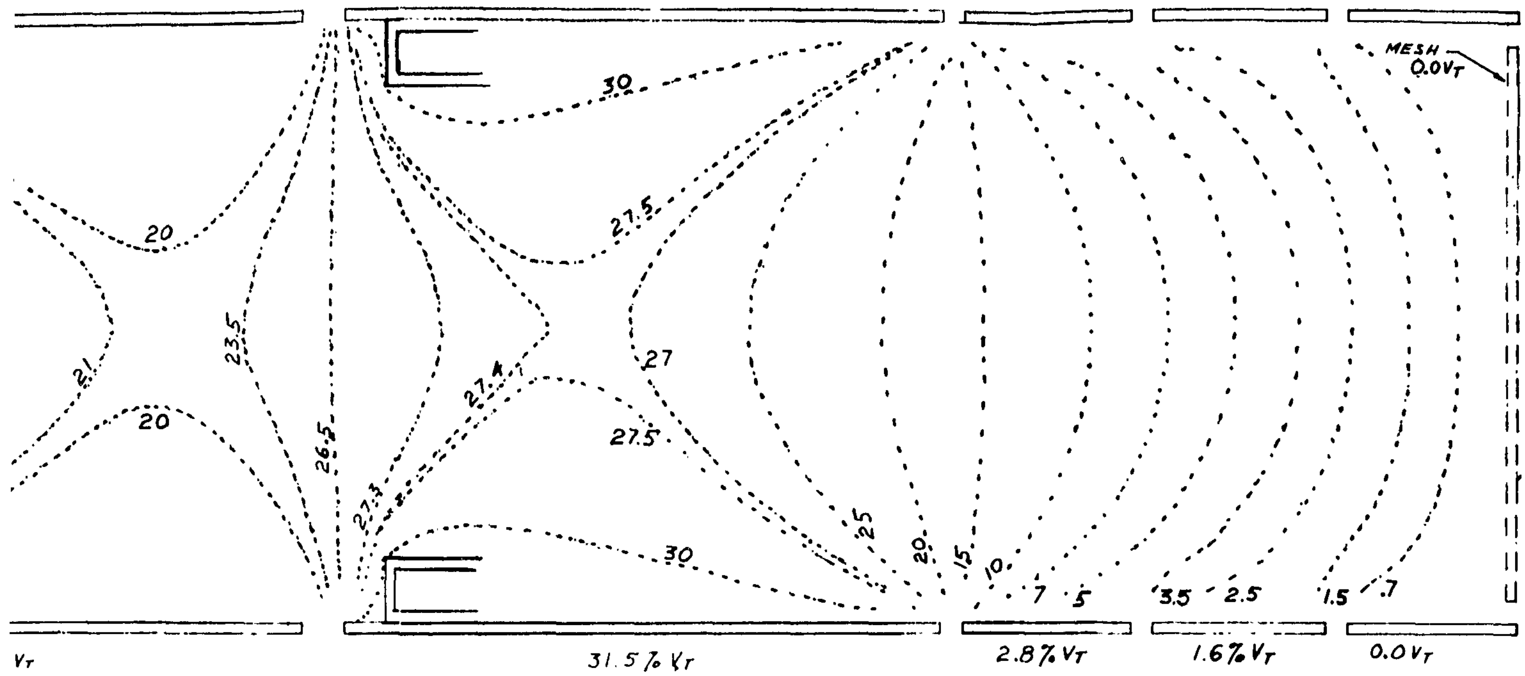


Figure 20. Equipotential plots of ele



gure 20. Equipotential plots of electrode c onfigurations.

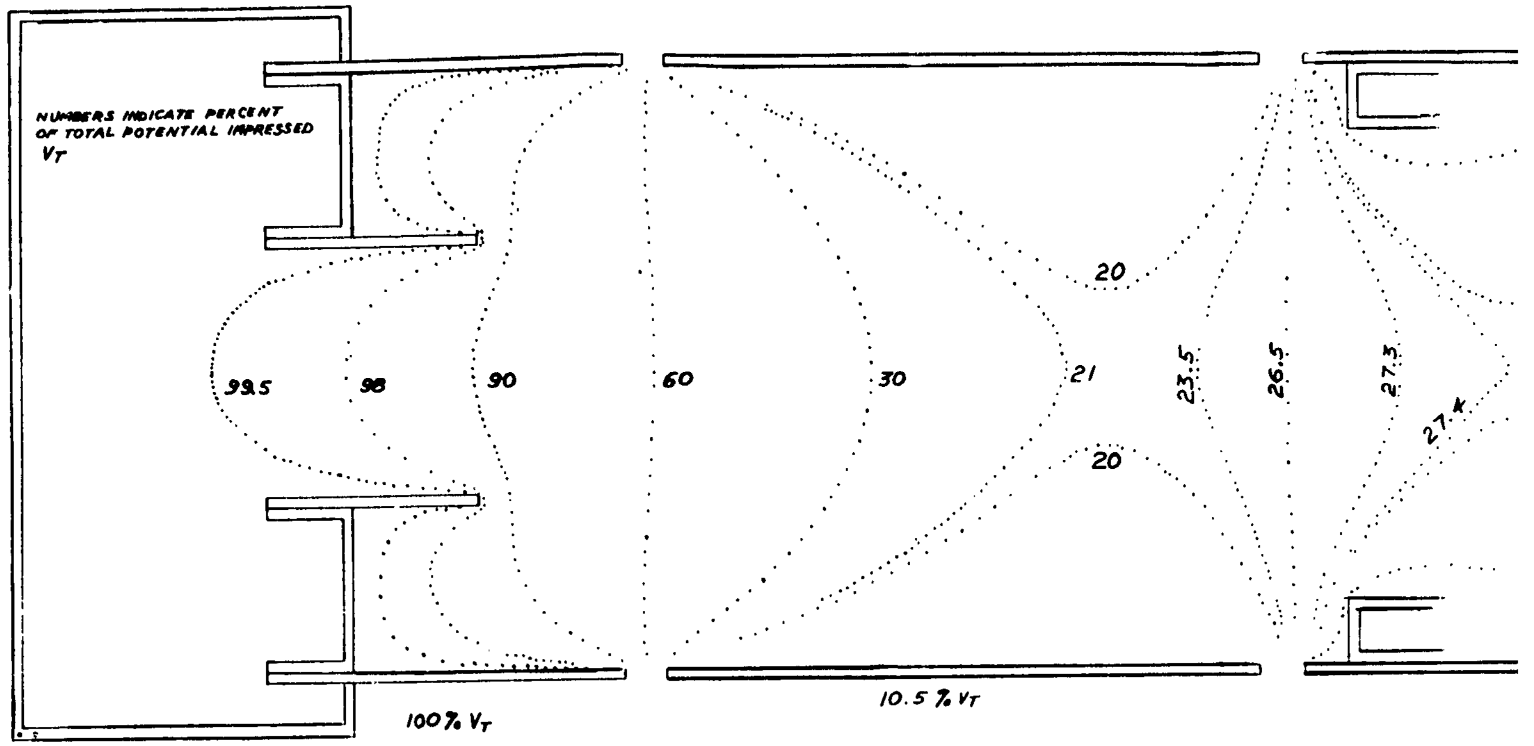
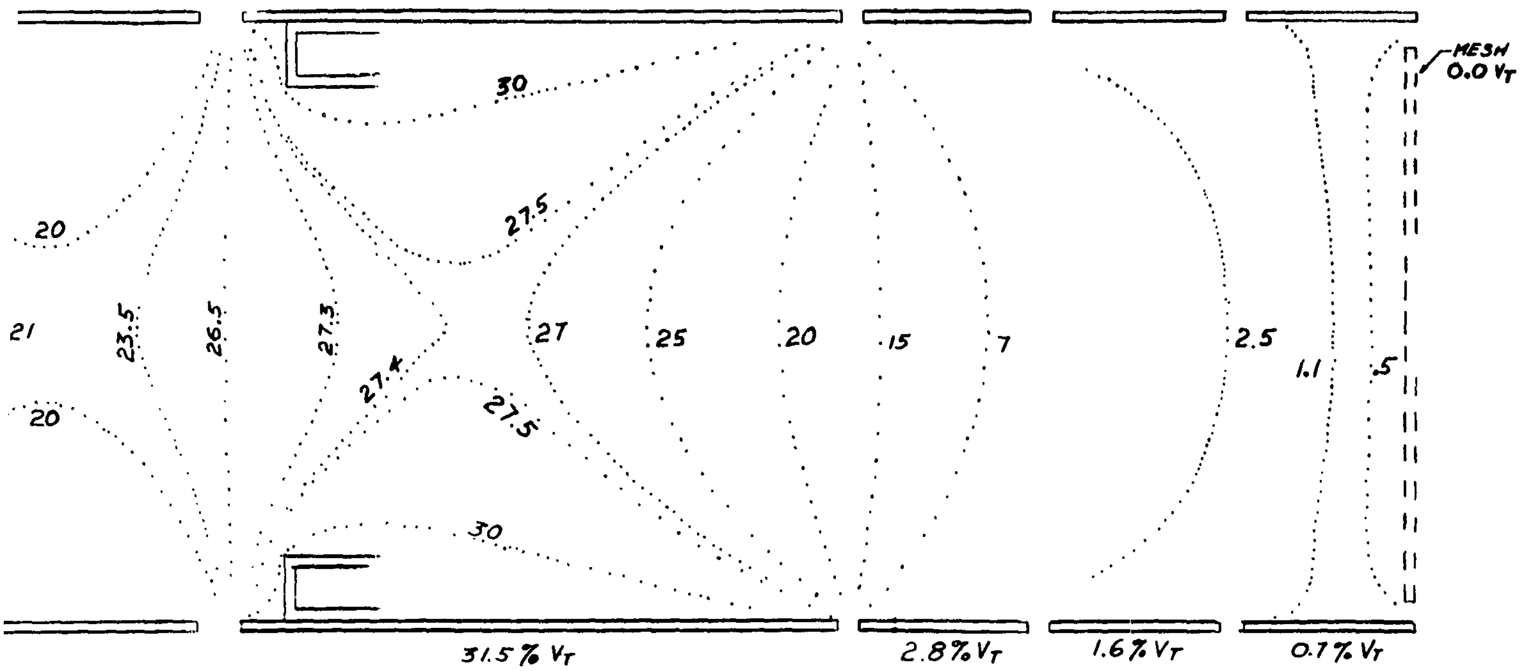


Figure 21. Equipotential plots of electrode confi



potential plots of electrode configurations.

2

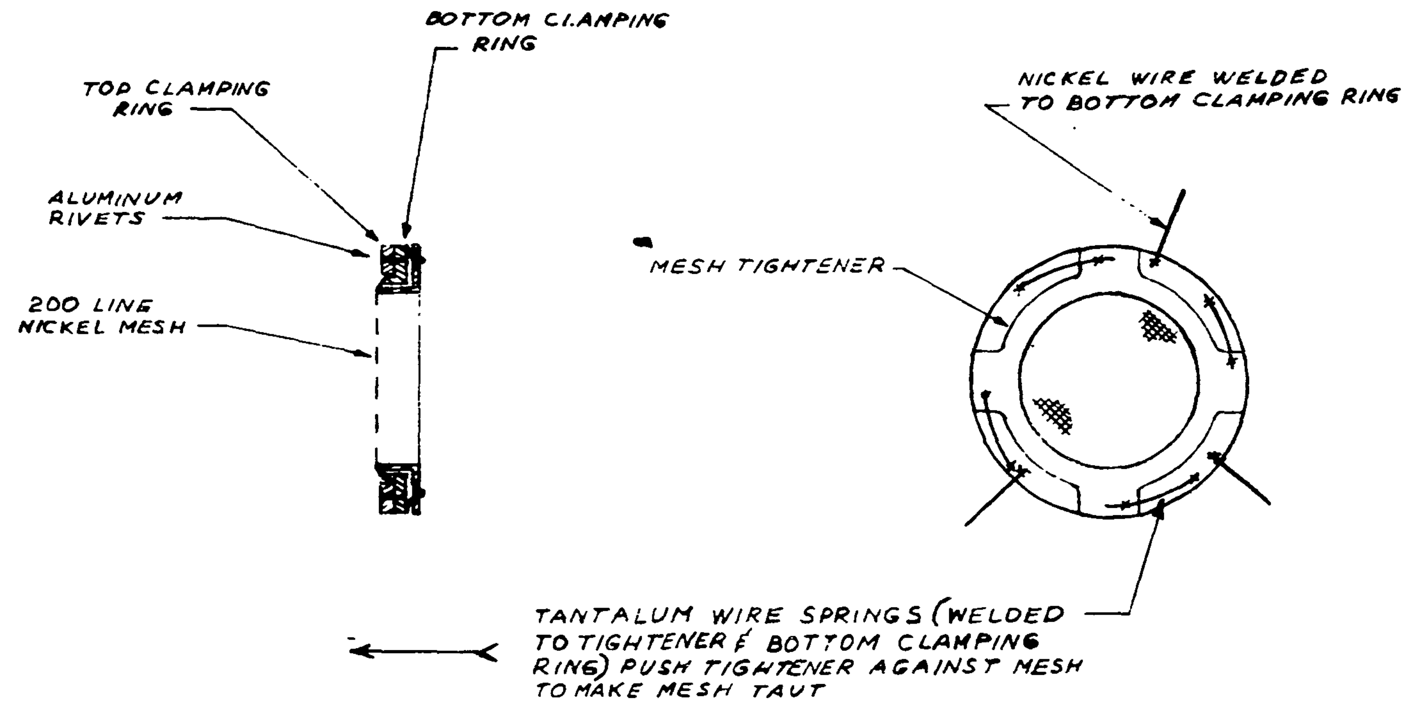


Figure 22. Sketch showing mounting of mesh.

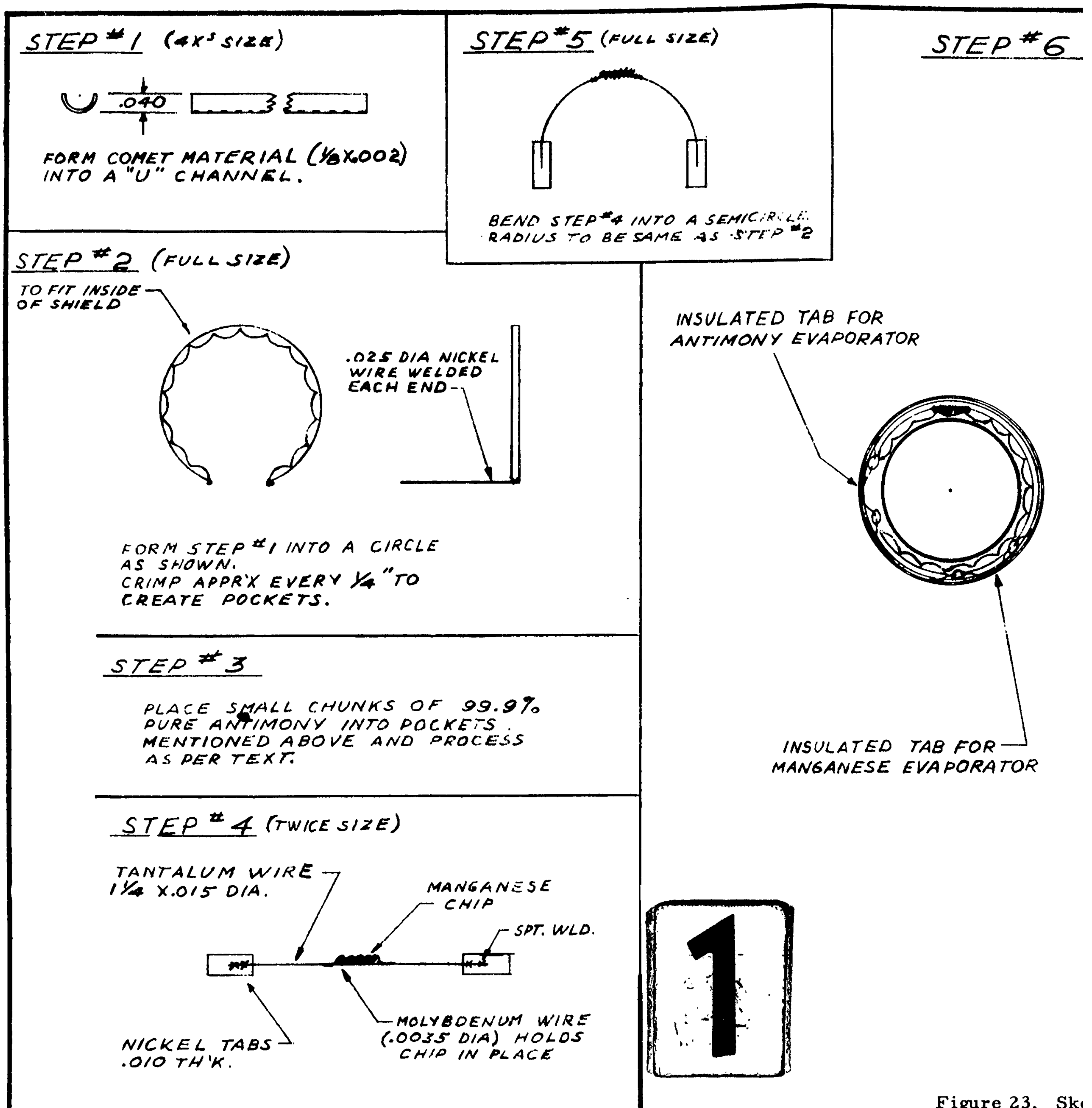

STEP #1 (4X'S SIZE)
.040
FORM COMET MATERIAL (1/8 X.002) INTO A "U" CHANNEL.
STEP #5 (FULL SIZE)
BEND STEP #4 INTO A SEMICIRCLE RADIUS TO BE SAME AS STEP #2
STEP #6
STEP #2 (FULL SIZE)
TO FIT INSIDE OF SHIELD
.025 DIA NICKEL WIRE WELDED EACH END
FORM STEP #1 INTO A CIRCLE AS SHOWN.
CRIMP APPR'X EVERY 1/4" TO CREATE POCKETS.
INSULATED TAB FOR ANTIMONY EVAPORATOR
STEP #3
PLACE SMALL CHUNKS OF 99.9% PURE ANTIMONY INTO POCKETS. MENTIONED ABOVE AND PROCESS AS PER TEXT.
INSULATED TAB FOR MANGANESE EVAPORATOR
STEP #4 (TWICE SIZE)
TANTALUM WIRE 1 1/4 X.015 DIA.
MANGANESE CHIP
SPT. WLD.
MOLYBDENUM WIRE (.0035 DIA) HOLDS CHIP IN PLACE
NICKEL TABS .010 TH'K.

Figure 23. Sk

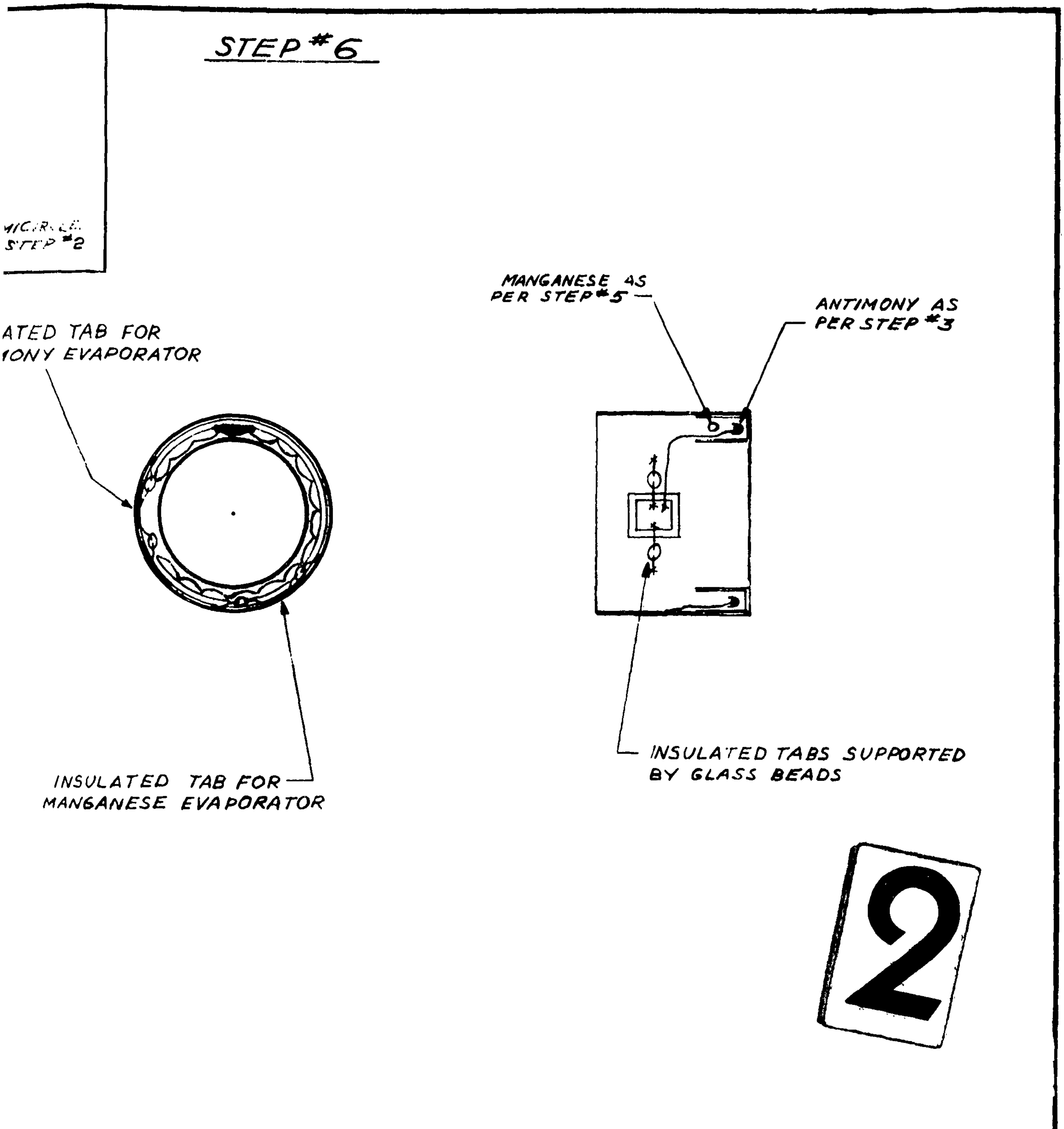


Figure 23. Sketch showing mounting of evaporators.

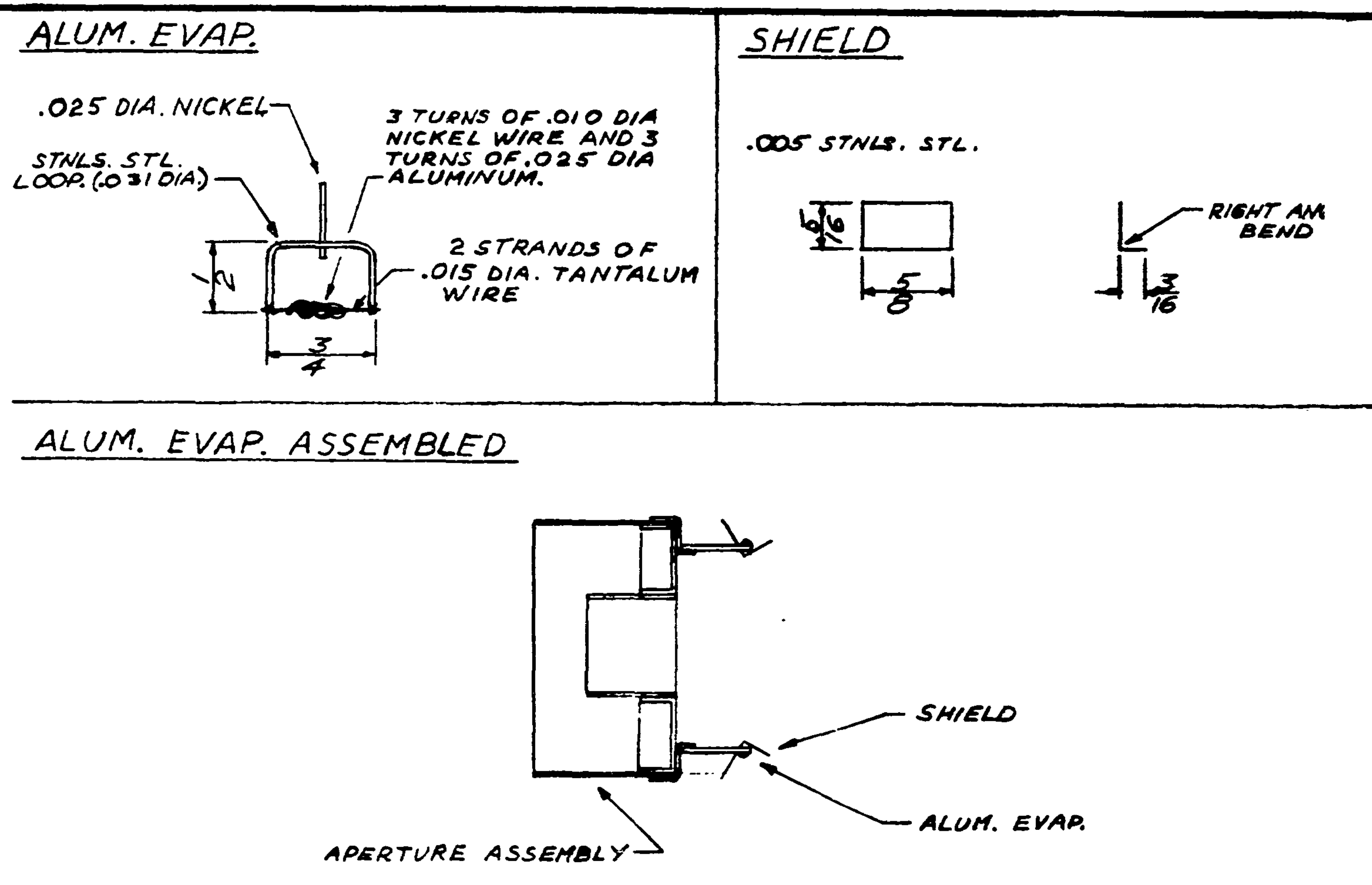


Figure 24. Sketch showing mounting of the Al-evaporator.

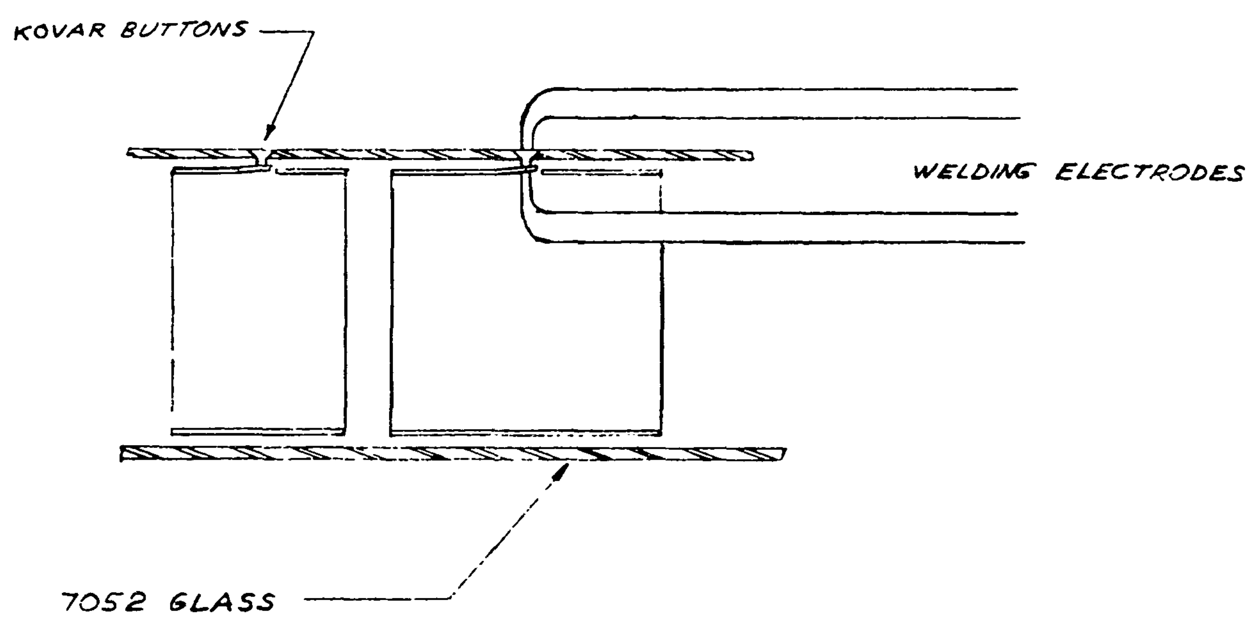


Figure 25. Sketch showing the welding of Kovar buttons.

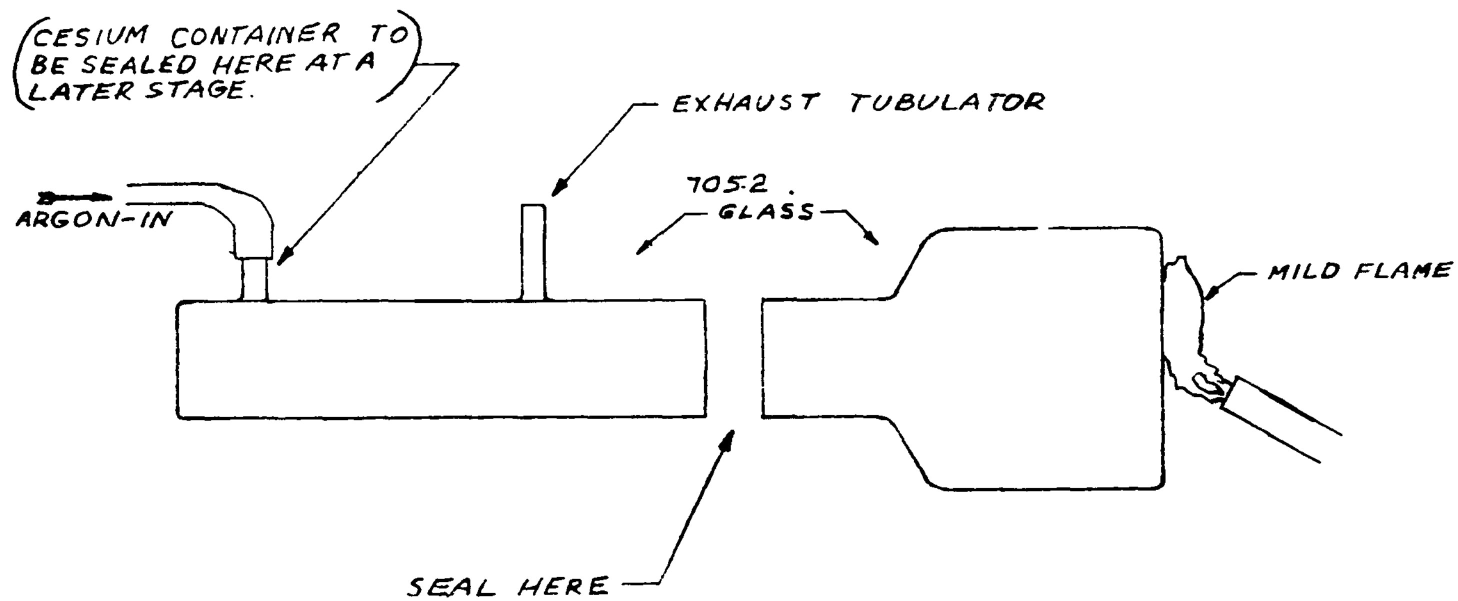


Figure 26. Sketch showing the sealing-in of the tube.

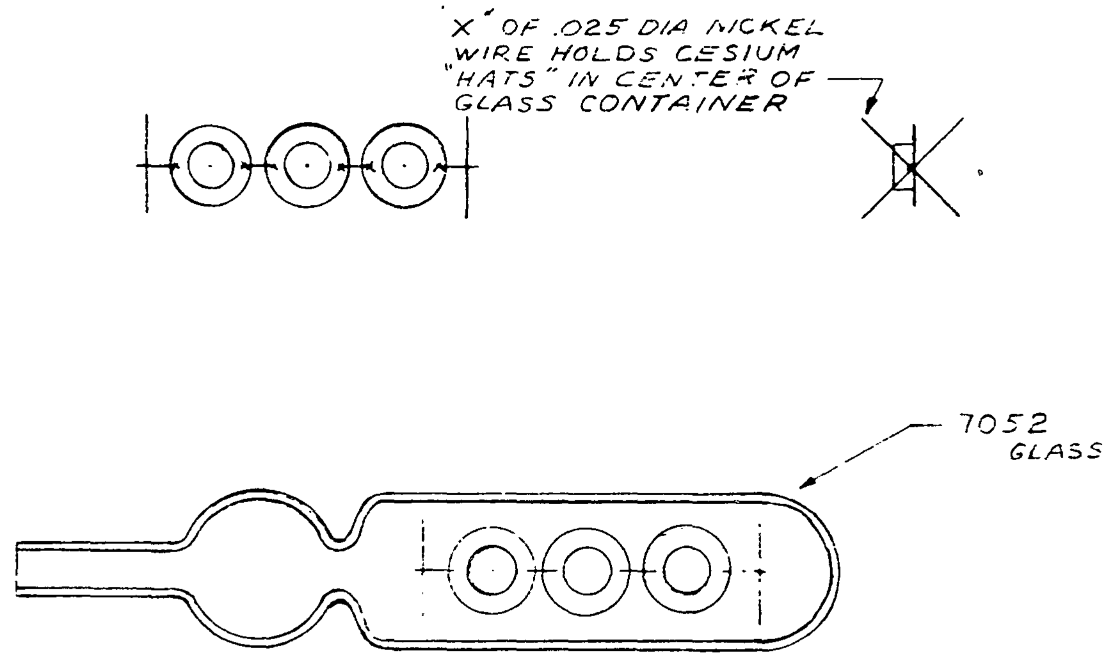


Figure 27. Sketch showing the Cs-pills.

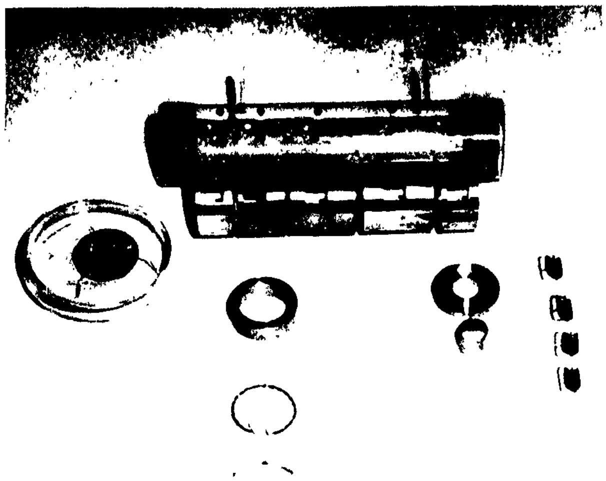
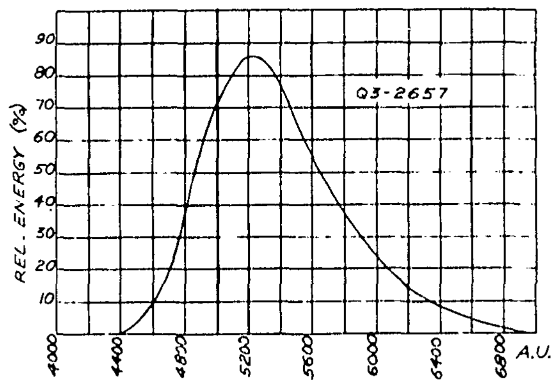


Figure 28. Shutter tube parts.



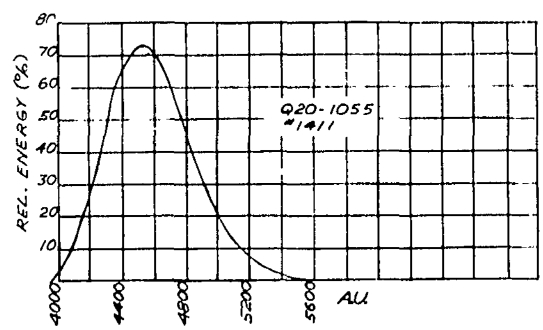


Figure 29. Special emission curves of Q3-2657 and Q20-1055 (#1411) phosphors

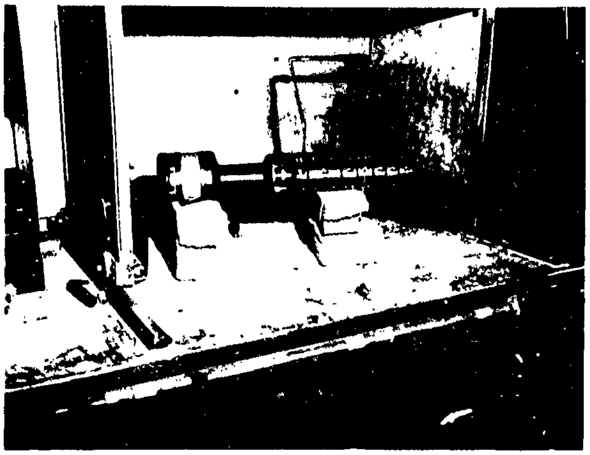


Figure 30. Shutter tubes in processing oven.

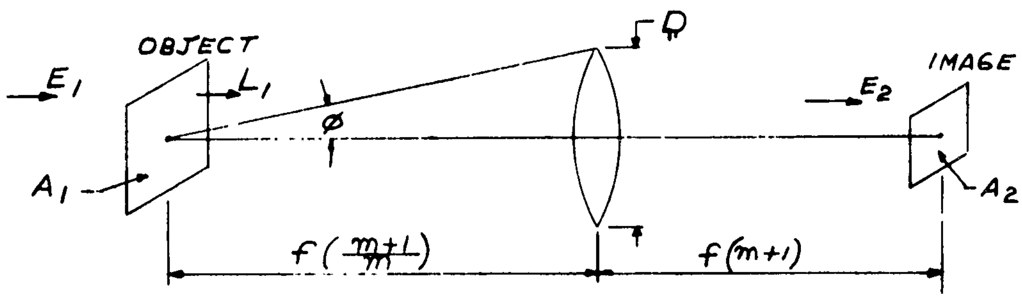


Figure 31. Schematic of light path in camera

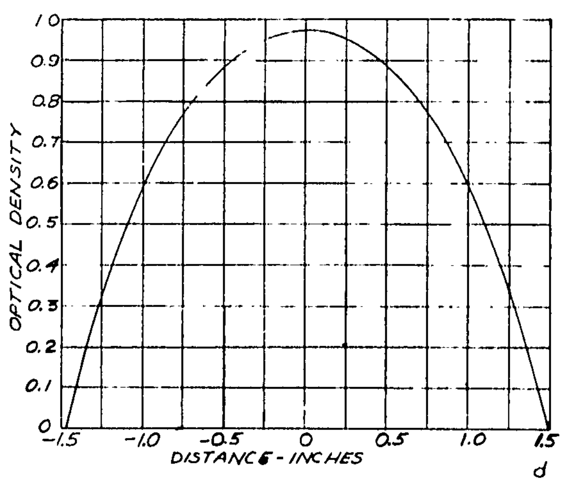


Figure 32. Measured density plot on photographic plate as a function of the distance from the center.

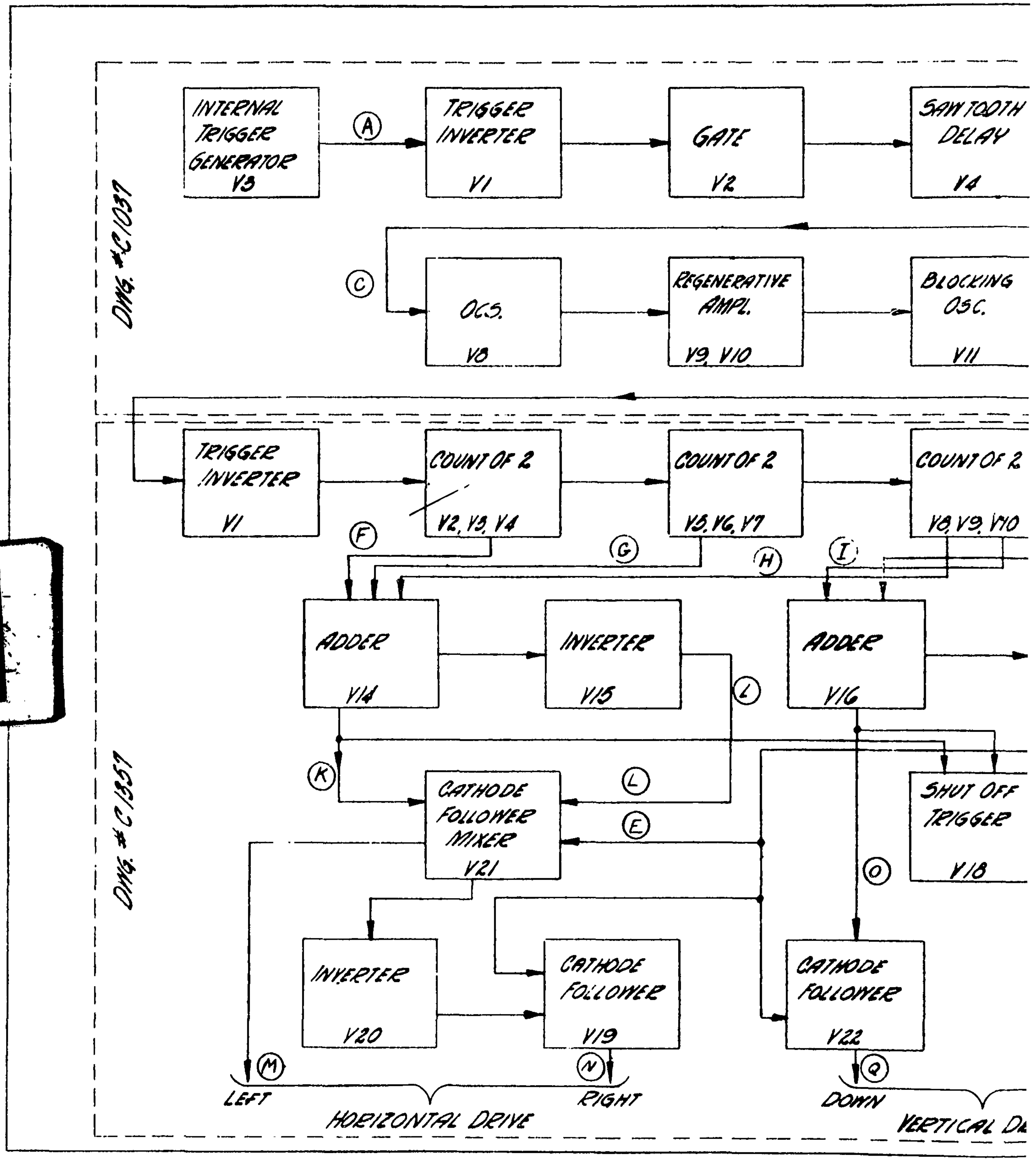
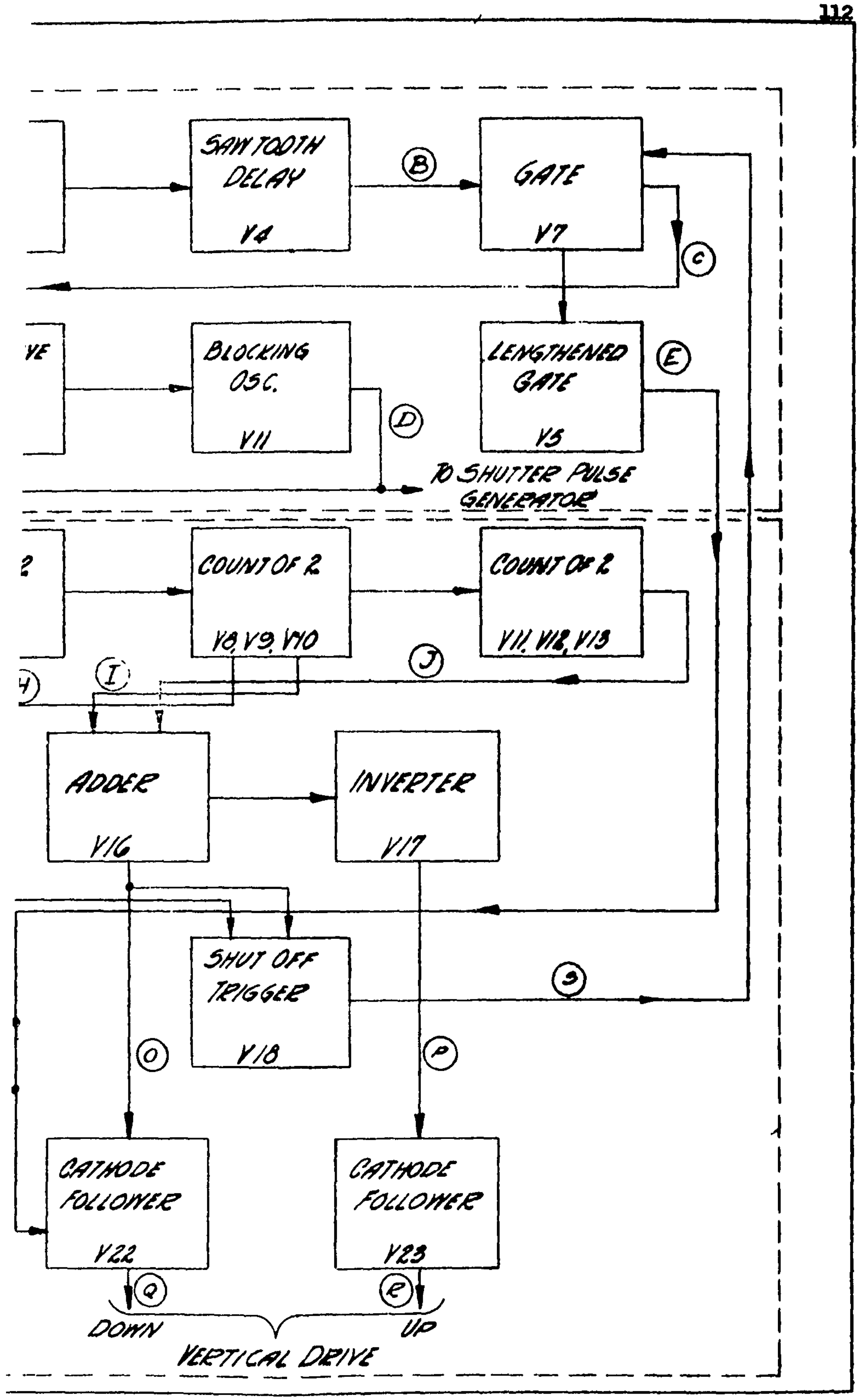


Figure 33. Block diagram of the synchronizer and the shaper circuits.


SAW TOOTH DELAY
V4
B
GATE
V7
C
VE
BLOCKING OSC.
V11
D
LENGTHENED GATE
V5
E
TO SHUTTER PULSE GENERATOR
COUNT OF 2
V8, V9, V10
COUNT OF 2
V11, V12, V13
I
J
ADDER
V16
INVERTER
V17
SHUT OFF TRIGGER
V18
S
O
P
CATHODE FOLLOWER
V22
CATHODE FOLLOWER
V23
Q
R
DOWN
UP
VERTICAL DRIVE

its.

2

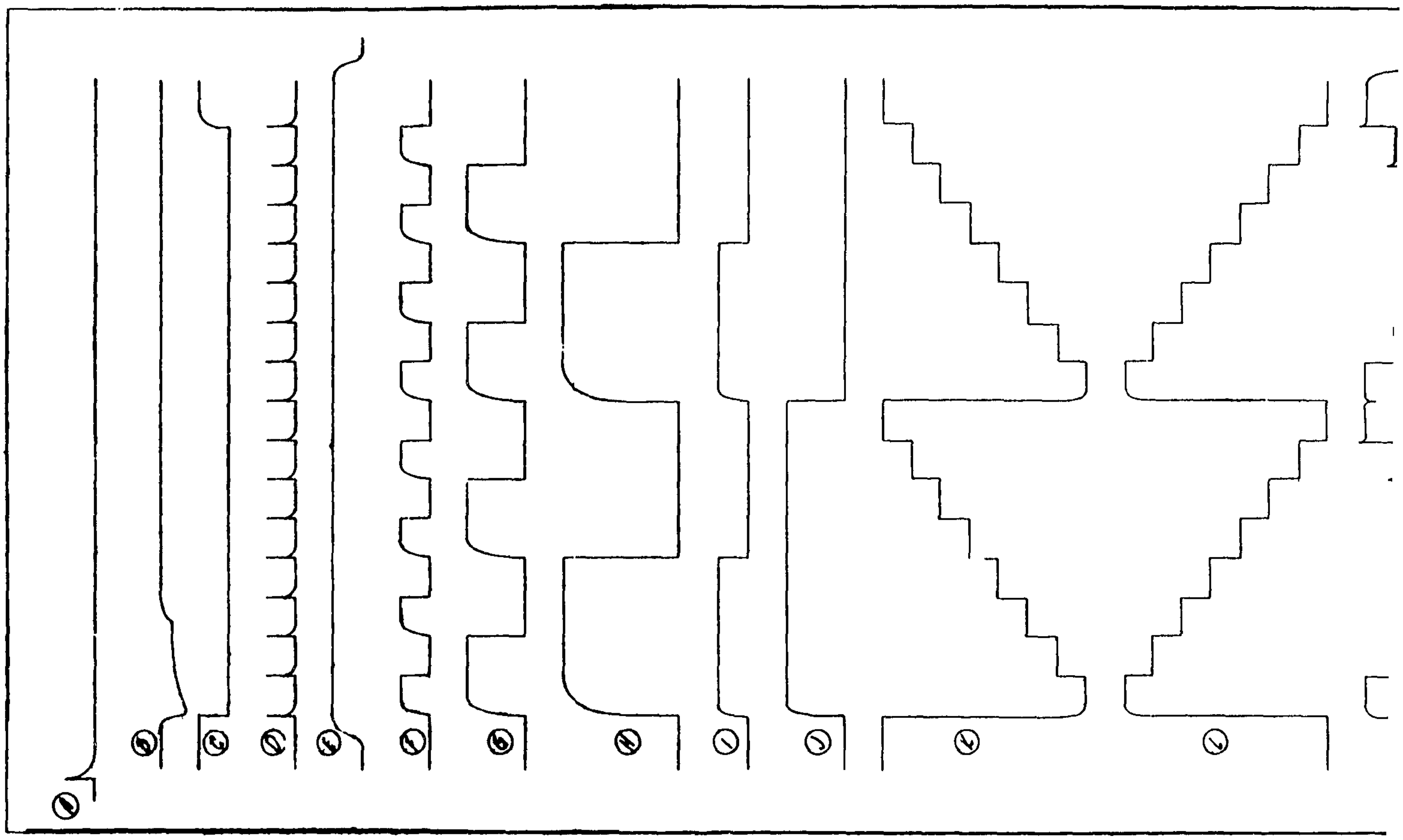
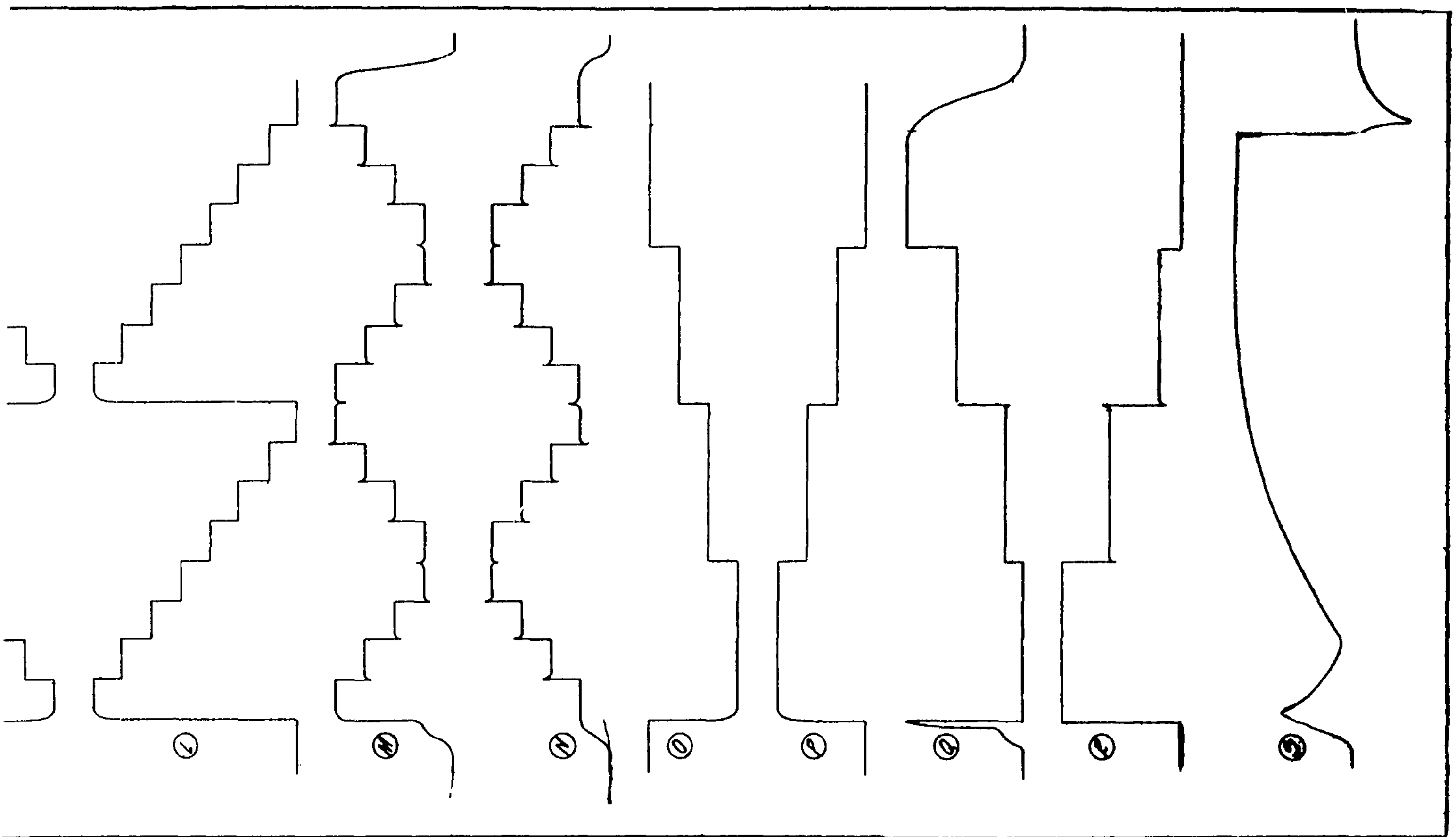


Figure 34. Waveforms of the synchronizer and the shaper circuits.



2

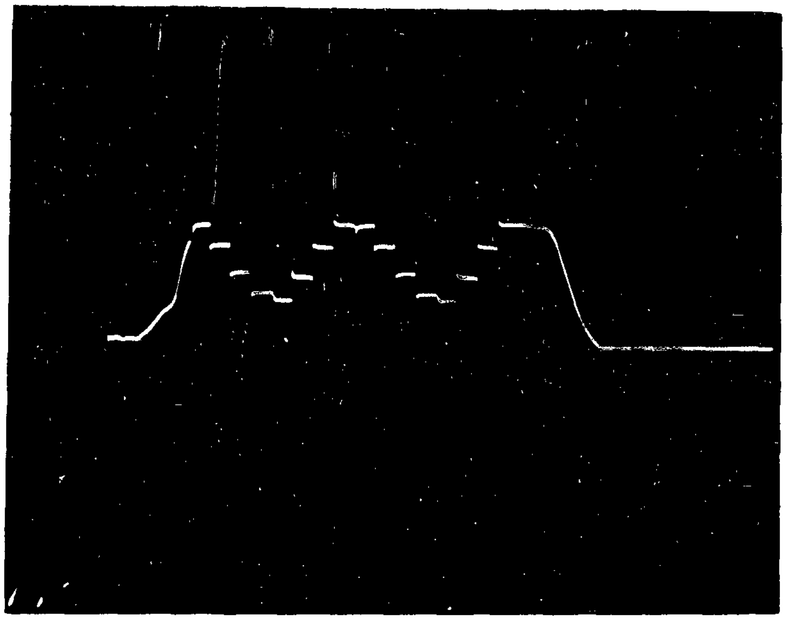


Figure 35. Left sweep input, horizontal axis 15 used/cm, vertical axis 5 V/cm

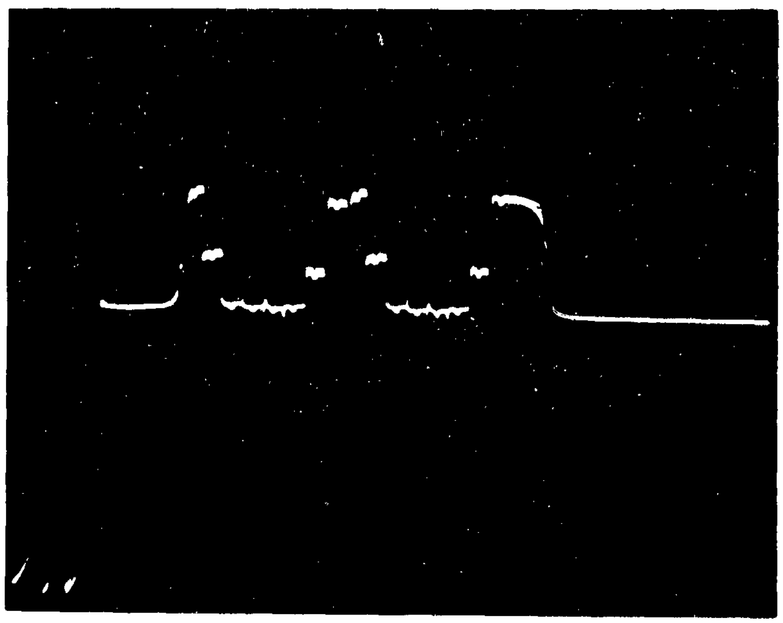


Figure 36. Left sweep cathode, horizontal axis 15 usec/cm, vertical axis 1.66 V/cm

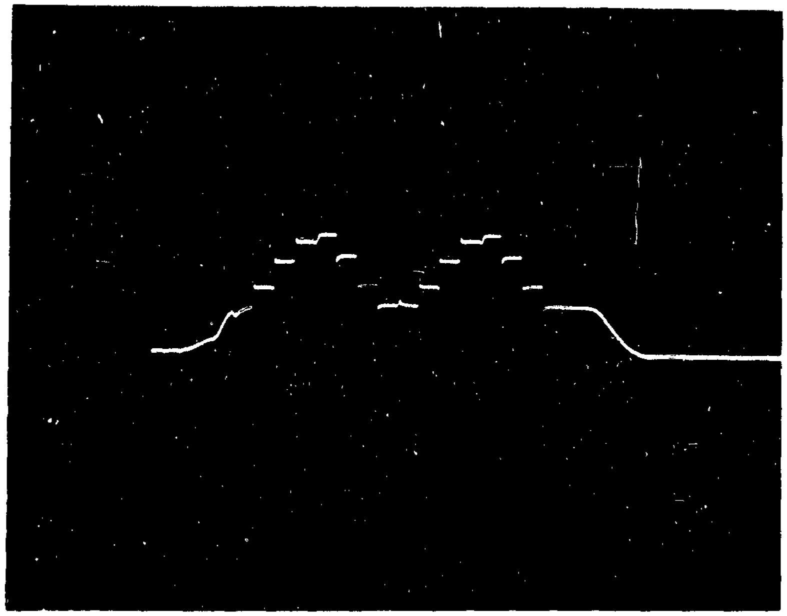


Figure 37. Right sweep input, horizontal axis 15 usec/cm, vertical axis 5 V/cm.

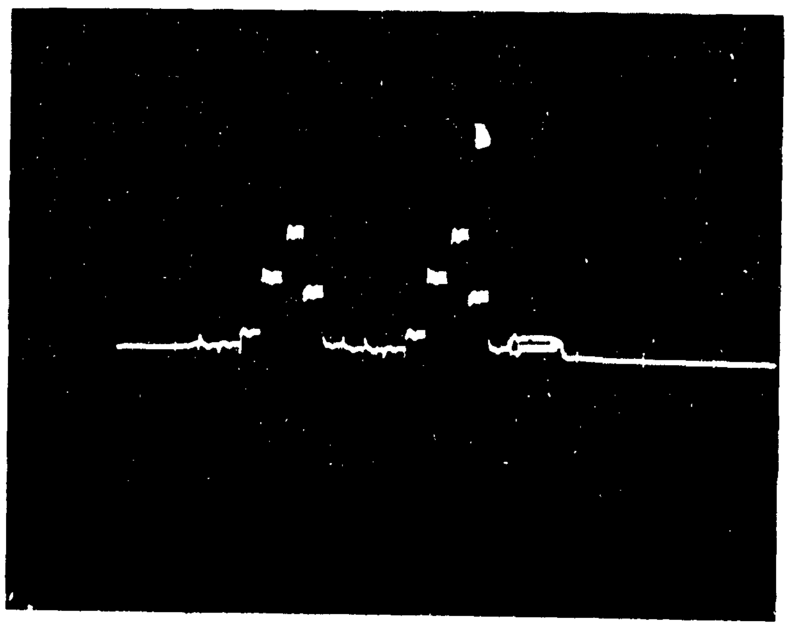


Figure 38. Right sweep cathode, horizontal axis 15 usec/cm, vertical axis 1. 66 V/cm

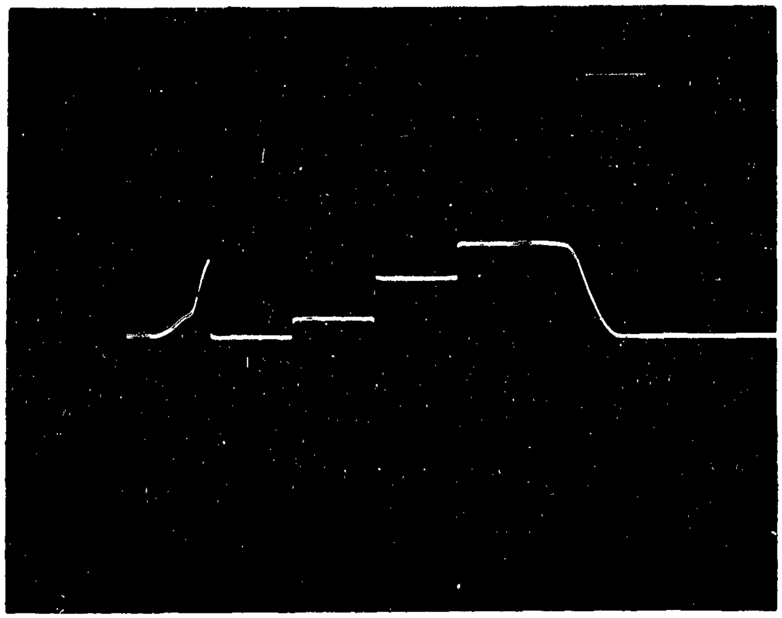


Figure 39. Down sweep input, horizontal axis 15 usec/cm, vertical axis 10 V/cm

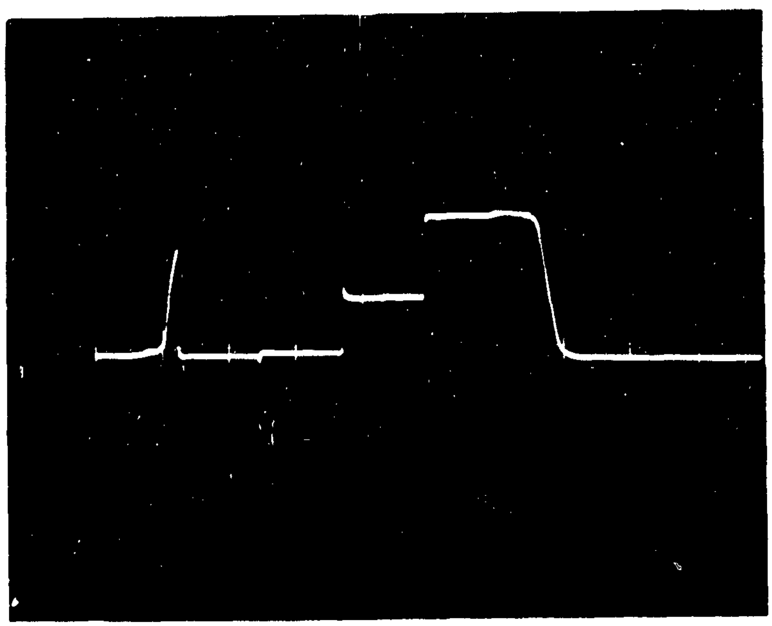


Figure 40. Down sweep cathode, horizontal axis 15 usec/cm, vertical axis 5 V/cm

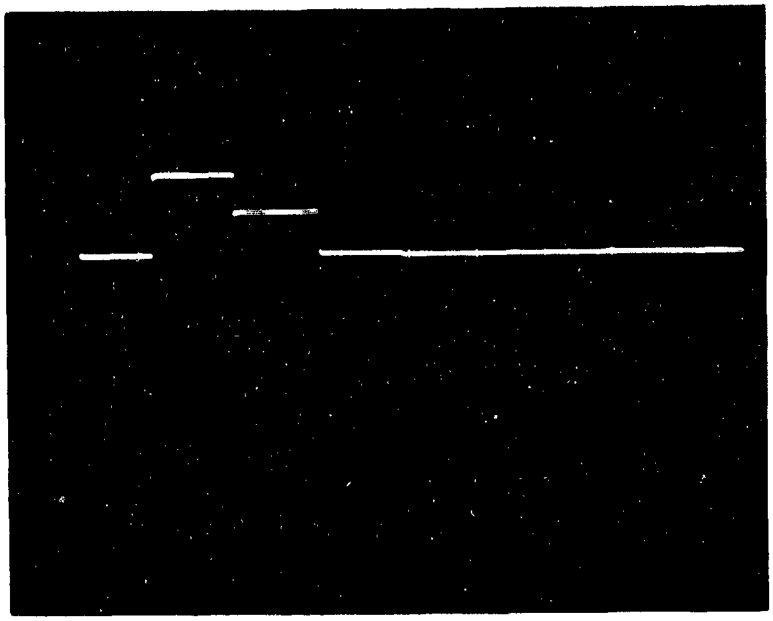


Figure 41. Up sweep input, horizontal axis 15 usec/cm, vertical axis 15 V/cm

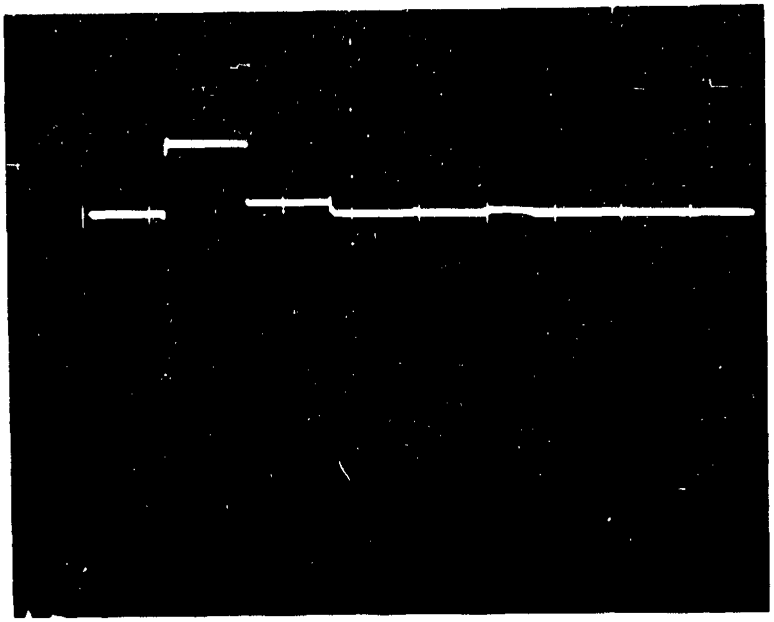


Figure 42. Up sweep cathode, horizontal axis 15 usec/cm, vertical axis 5 V/cm

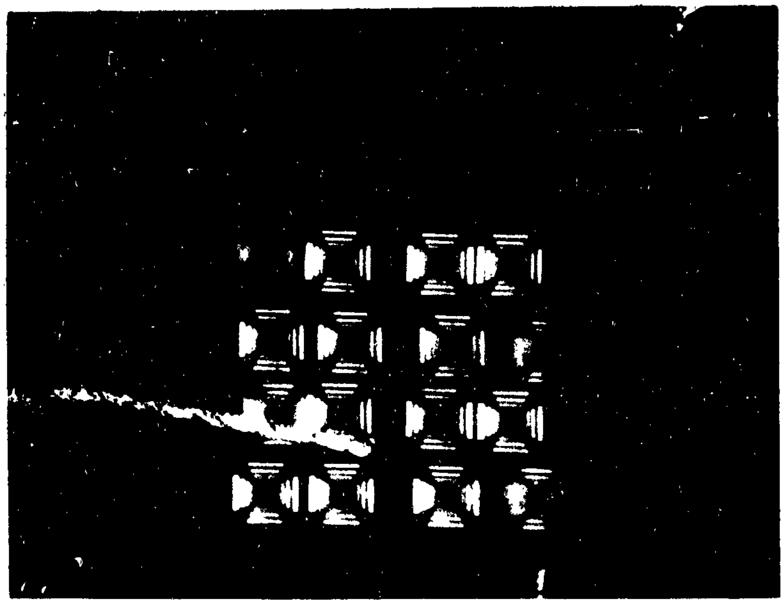
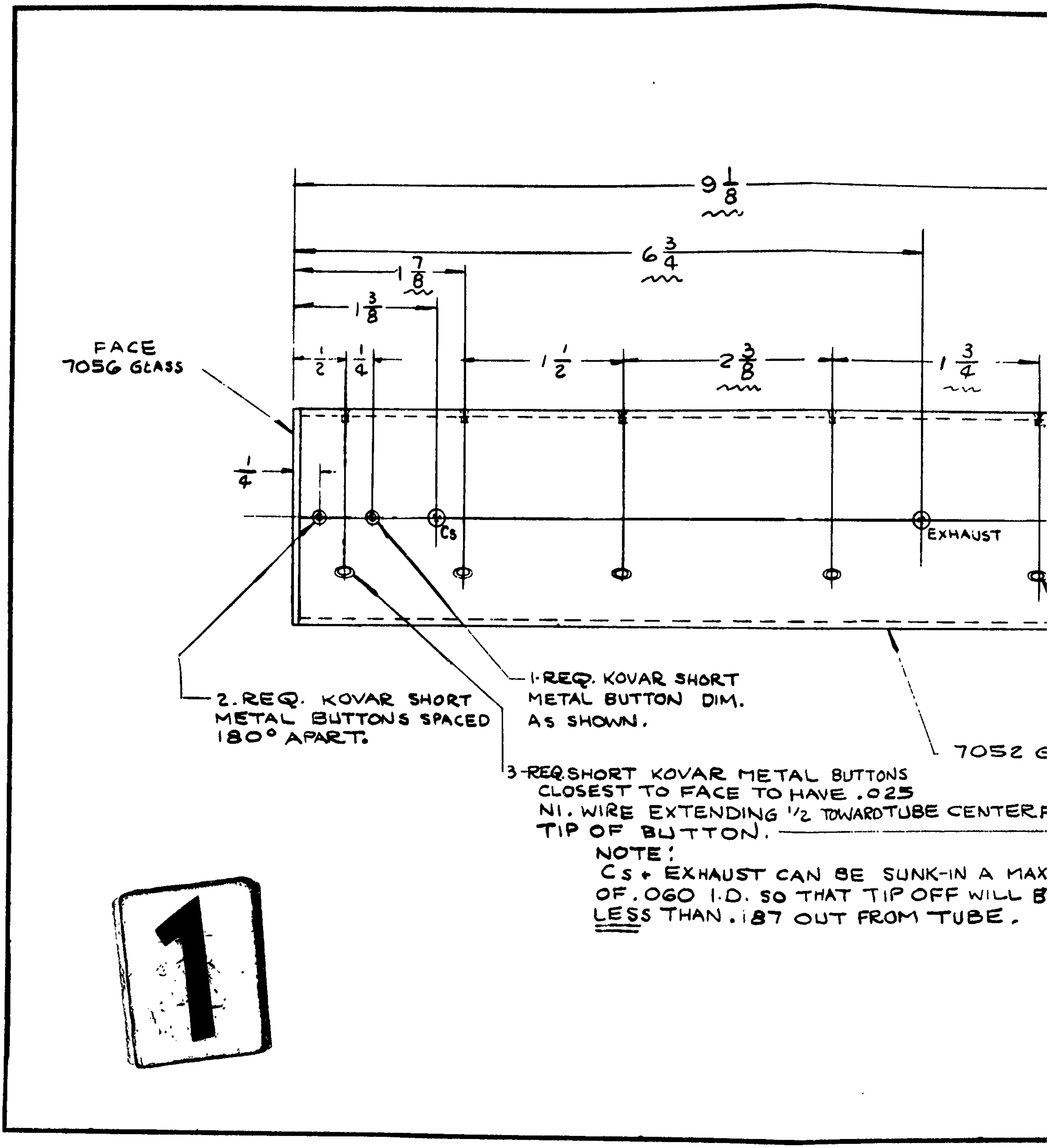
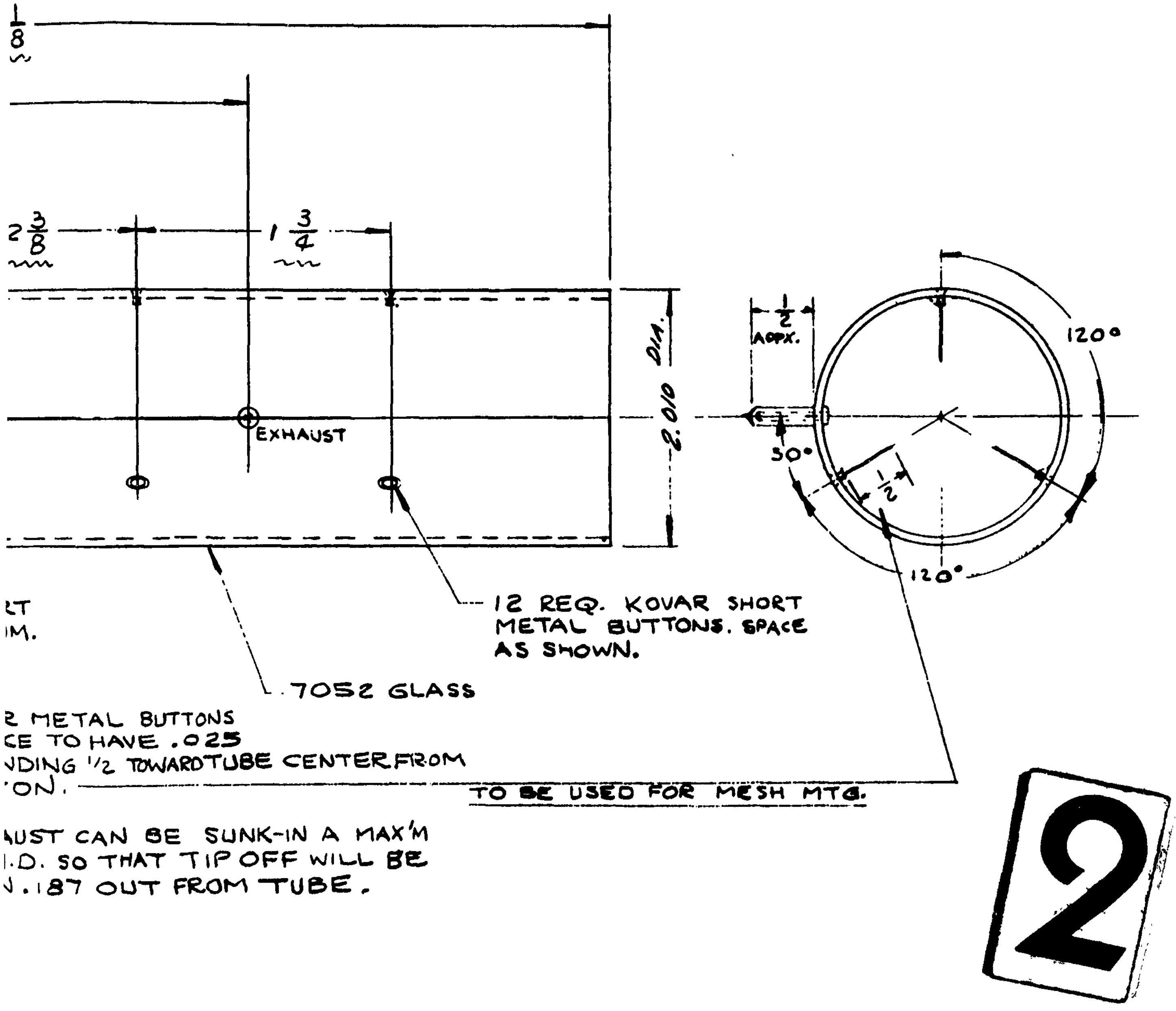
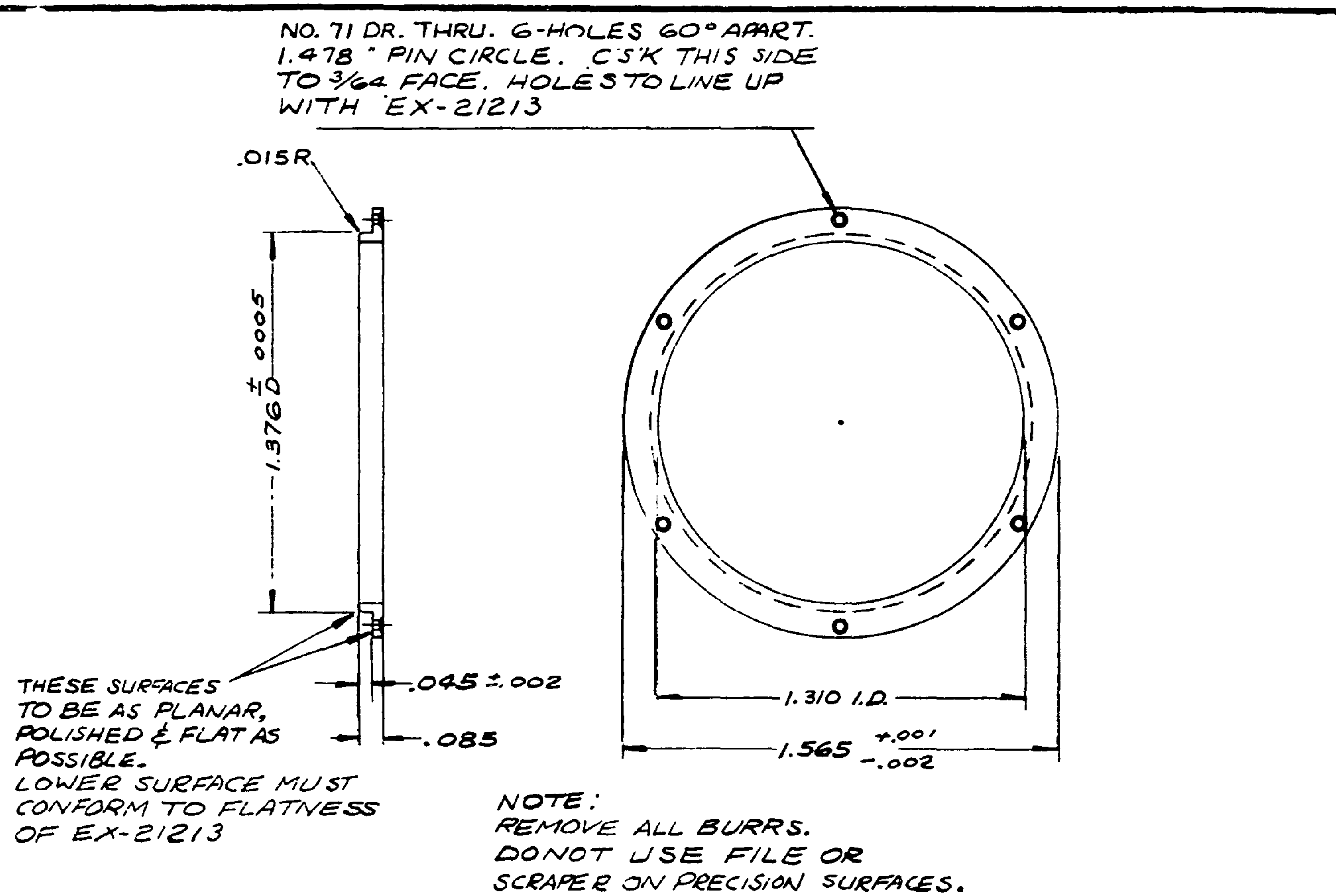


Figure 43. Tube 2-7-55. Slide projector continuously illuminating photocathode; tube running continuously; 16 frames, 0.3 usec pulse duration, 4.6 usec frame period; pulse delayed 1.3 usec. (Shows four bad frames due to horizontal sweep transients.)

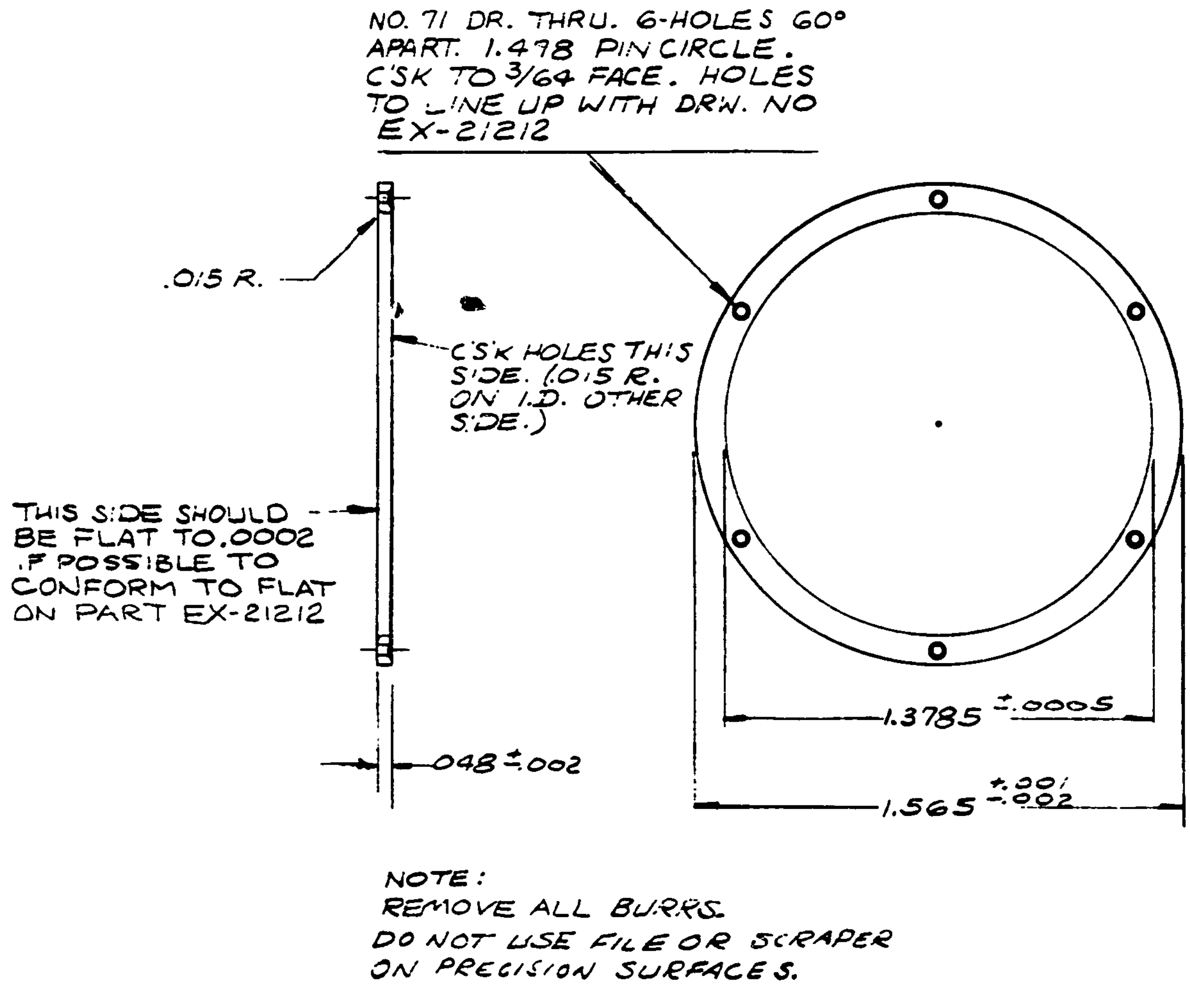

9 1/8
6 3/4
1 7/8
1 3/8
FACE
7056 GLASS
1/2
1/4
1 1/2
2 3/8
1 3/4
1/4
CS
EXHAUST
2. REQ. KOVAR SHORT METAL BUTTONS SPACED 180° APART.
1-REQ. KOVAR SHORT METAL BUTTON DIM. AS SHOWN.
7052 G
3-REQ. SHORT KOVAR METAL BUTTONS CLOSEST TO FACE TO HAVE .025 NI. WIRE EXTENDING 1/2 TOWARD TUBE CENTER F
TIP OF BUTTON.
NOTE:
CS + EXHAUST CAN BE SUNK-IN A MAX
OF .060 I.D. SO THAT TIP OFF WILL B
LESS THAN .187 OUT FROM TUBE.
1



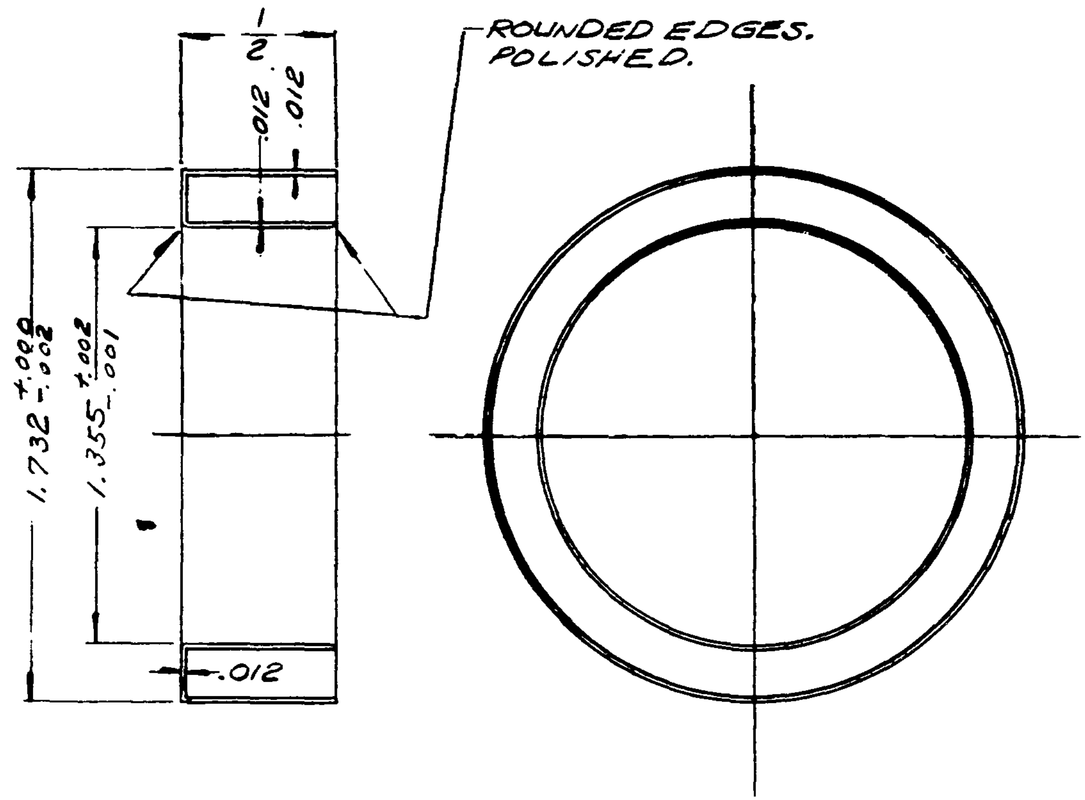
Drawing EX-21214 Electrode section in glass envelope.



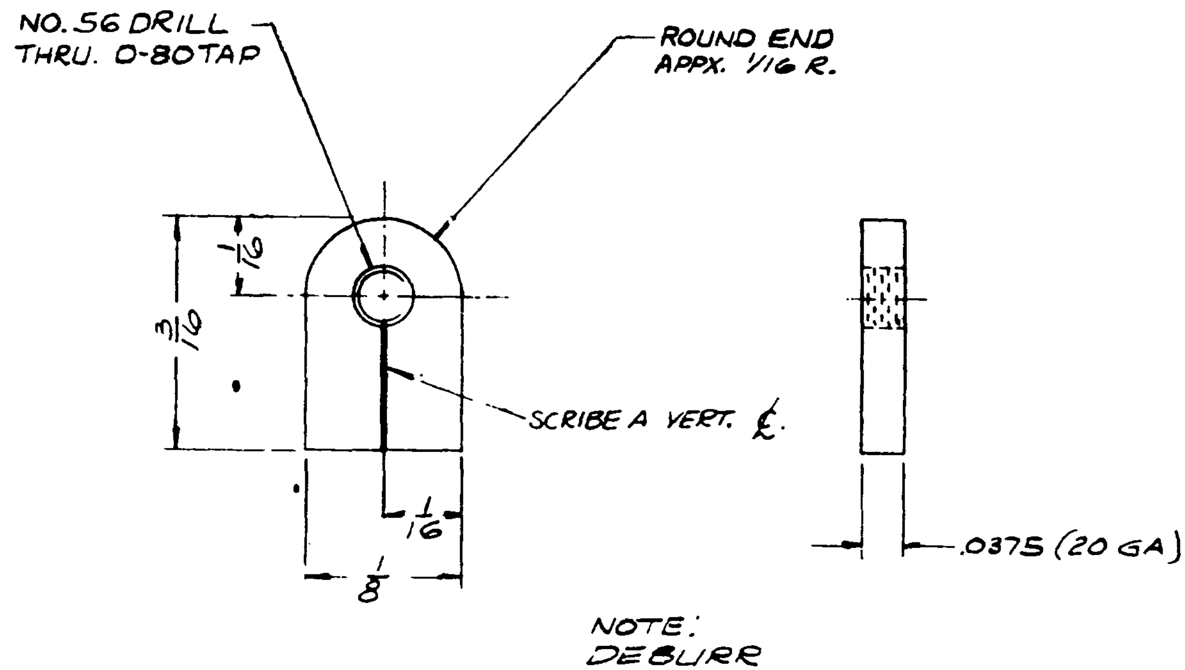
Drawing 21212 Tension ring



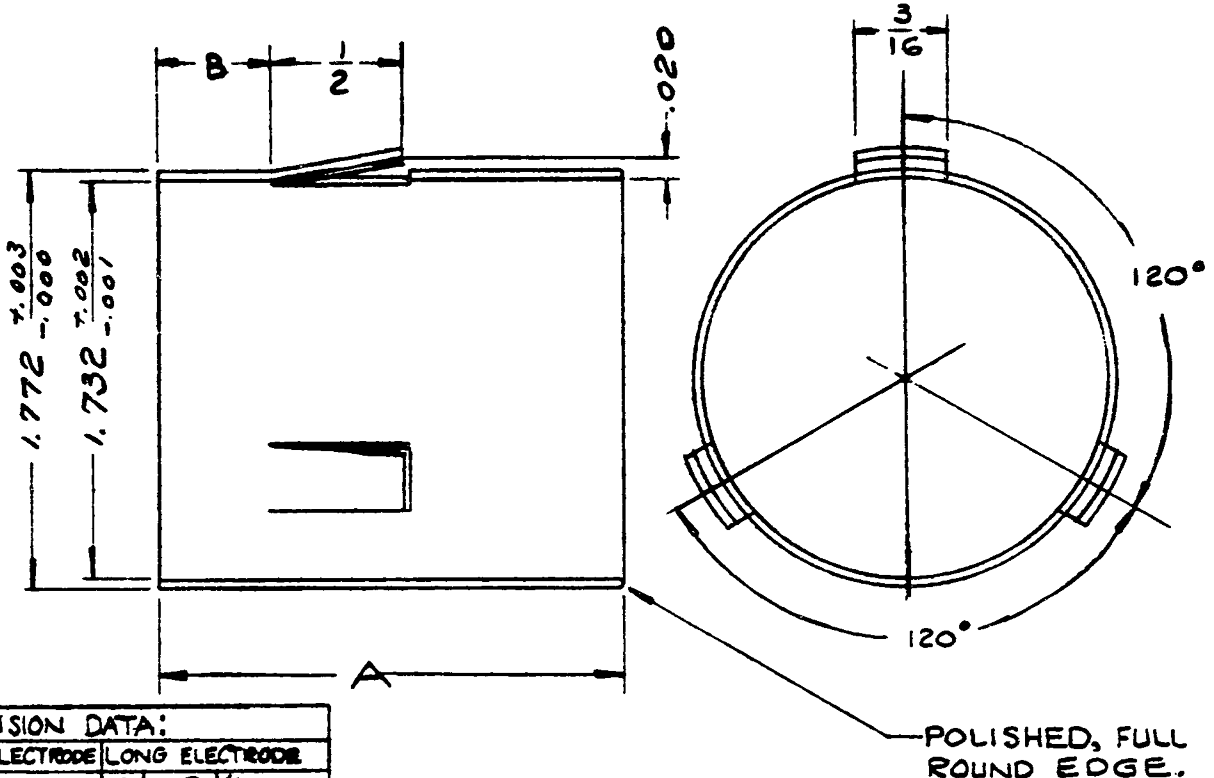
Drawing EX-21213 Clamping ring



Drawing EX-21210 Evaporator shield ring

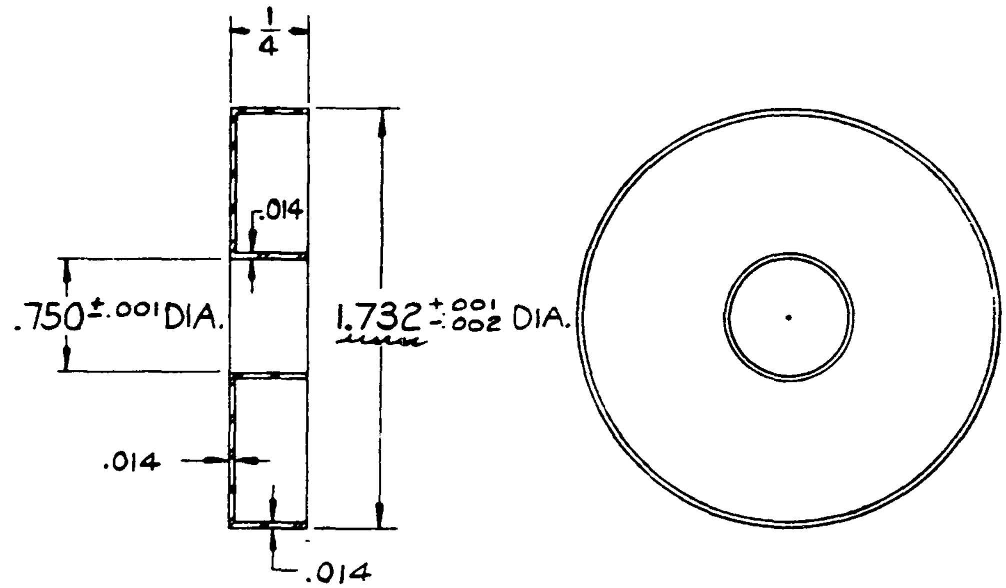


Drawing EX-21211 Mounting tab

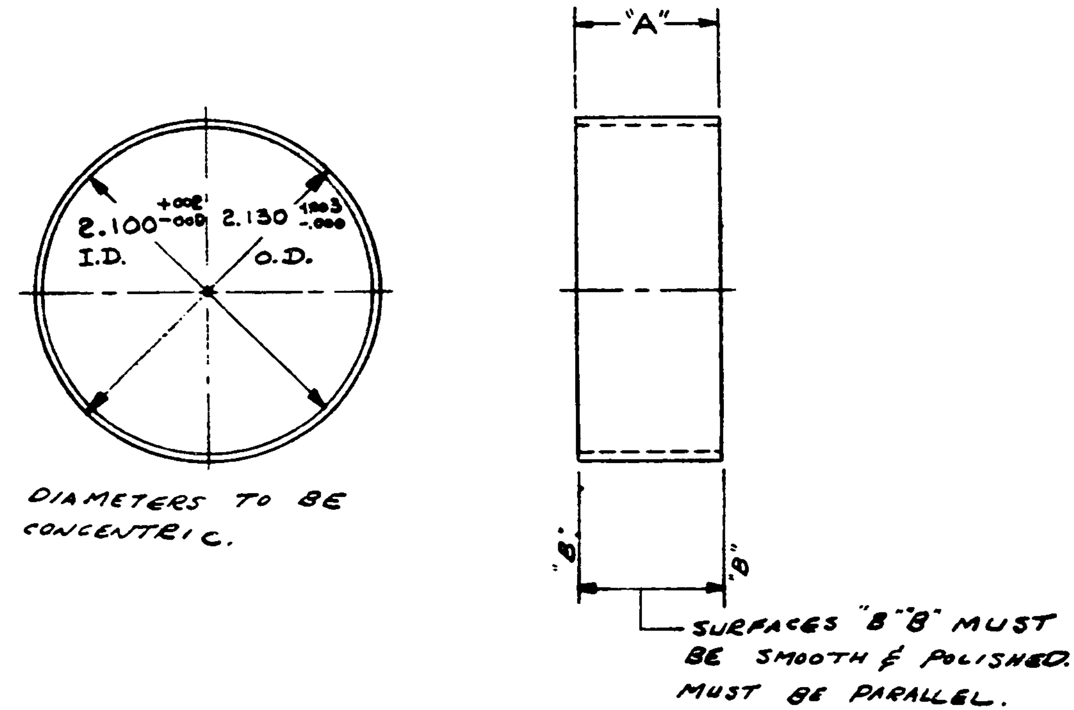


DIMENSION DATA:			
SHORT ELECTRODE		LONG ELECTRODE	
A	1 3/8	A	2 1/4
B	1/4	B	7/8

Drawing EX-21215 Accelerating electrode



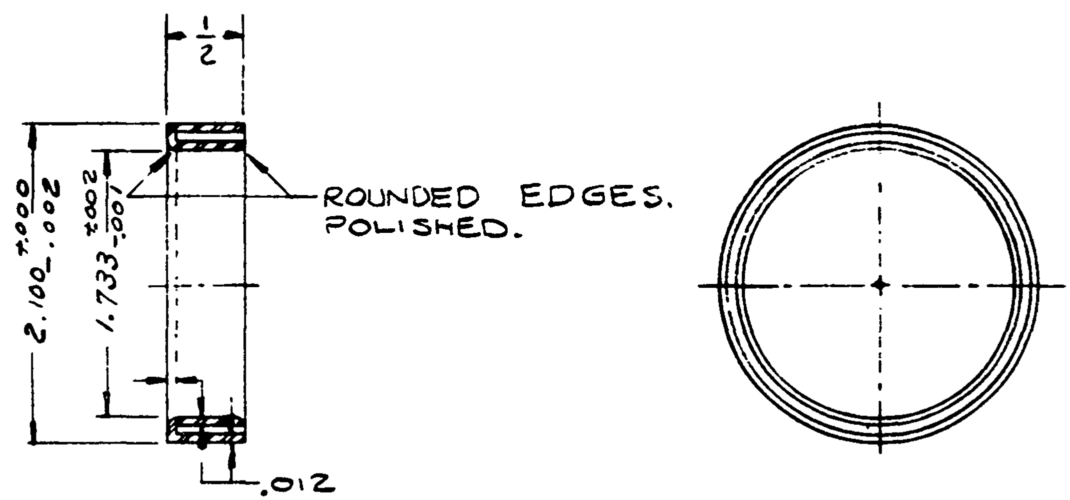
Drawing EX-21209 Aperture retaining ring



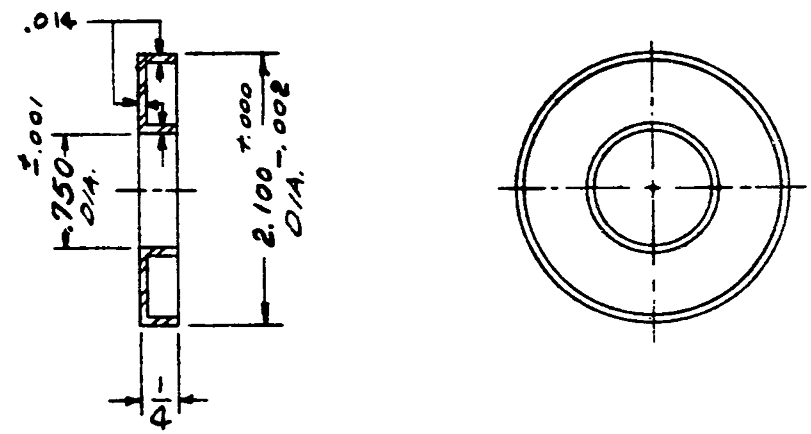
PART NO.	"A"
EX-21257-1	.781
EX-21257-2	1.593
EX-21257-3	2.625
EX-212574	1.187

DIMENSION DATA

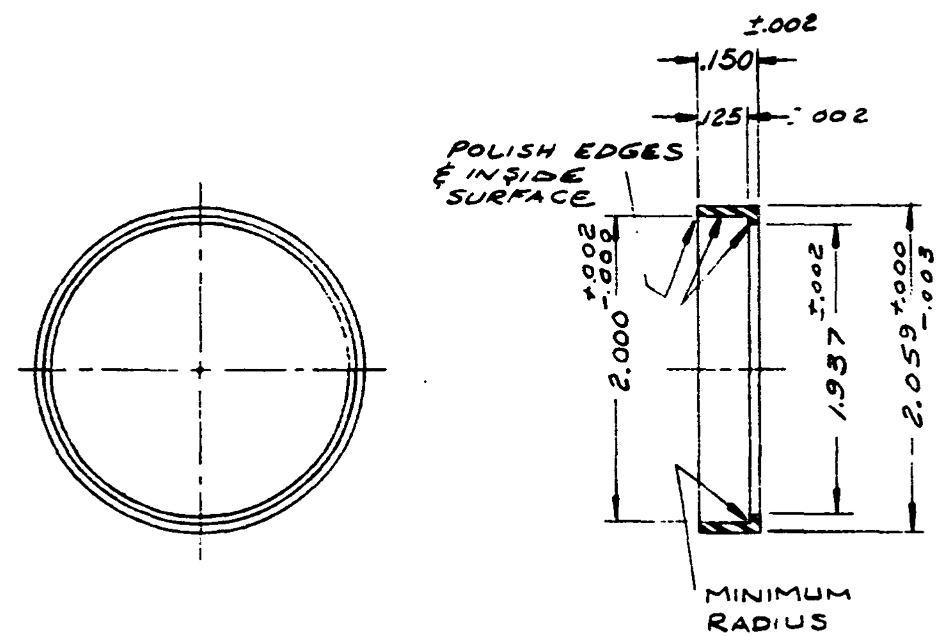
Drawing EX-21257 Focusing electrodes



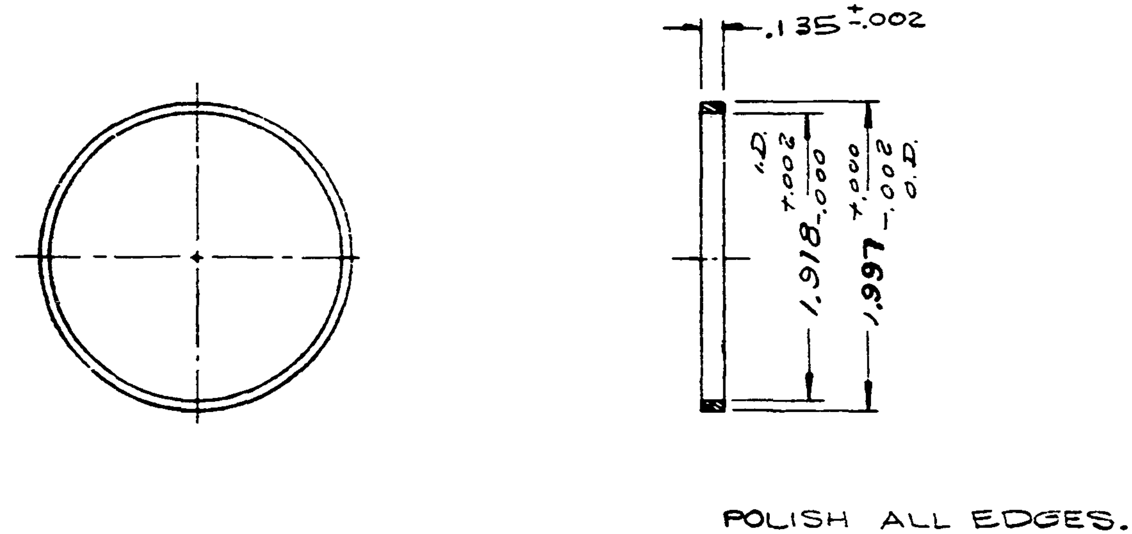
Drawing EX-21258 Evaporator shielding



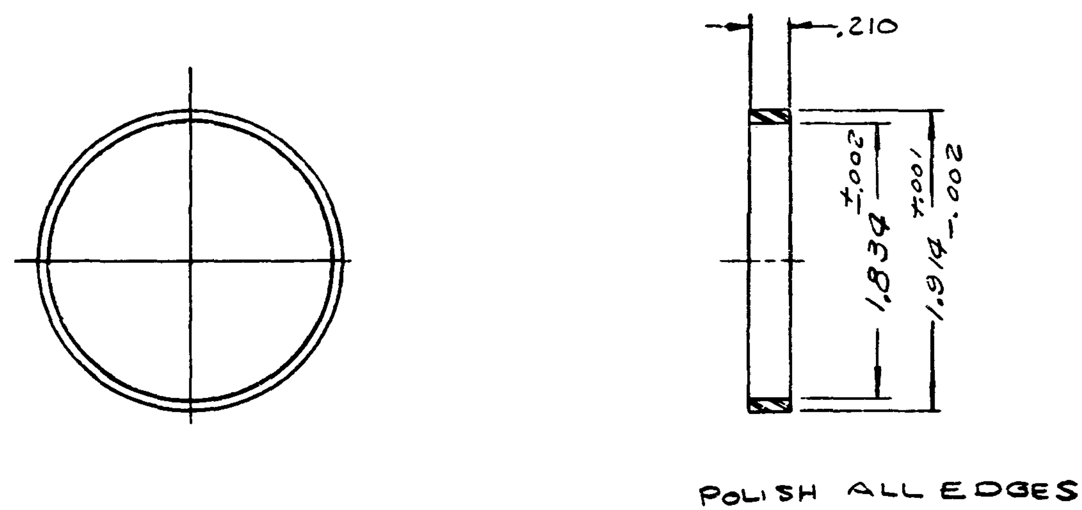
Drawing EX-21259 Aperture retainer disc



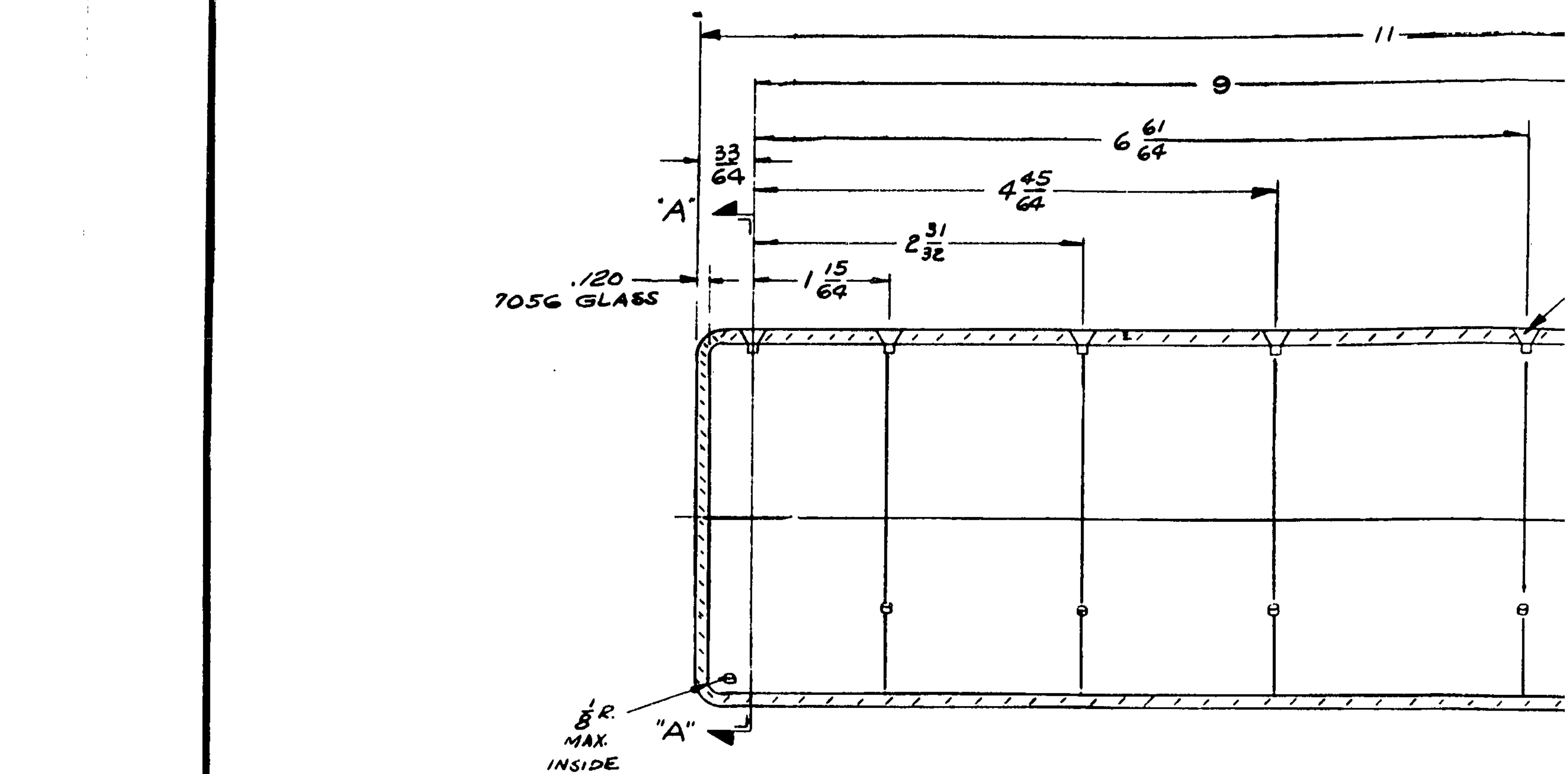
Drawing EX-21268 Mesh ring # 2

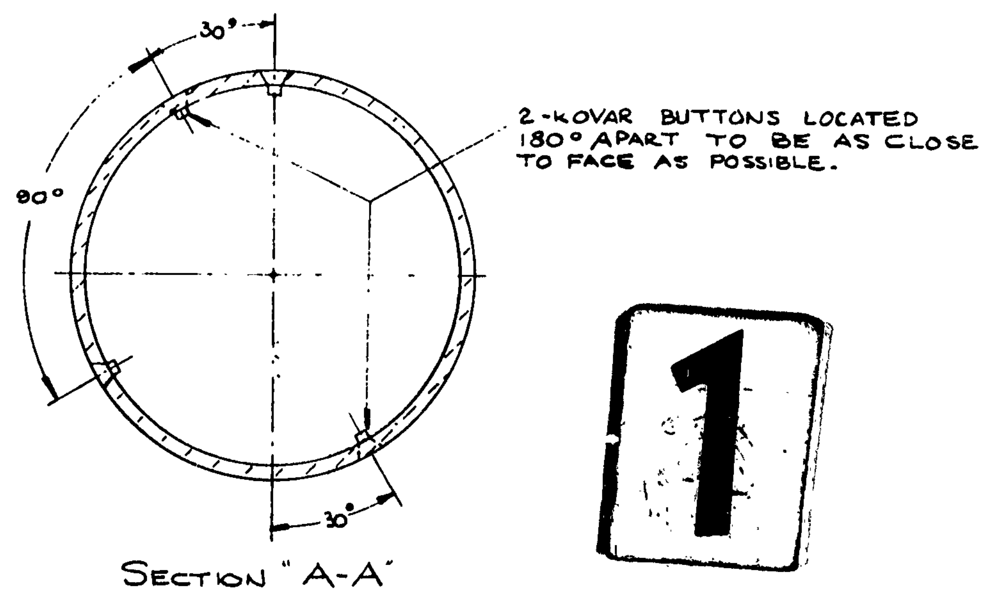


Drawing EX-21269 Mesh ring # 1

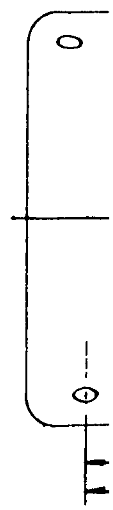


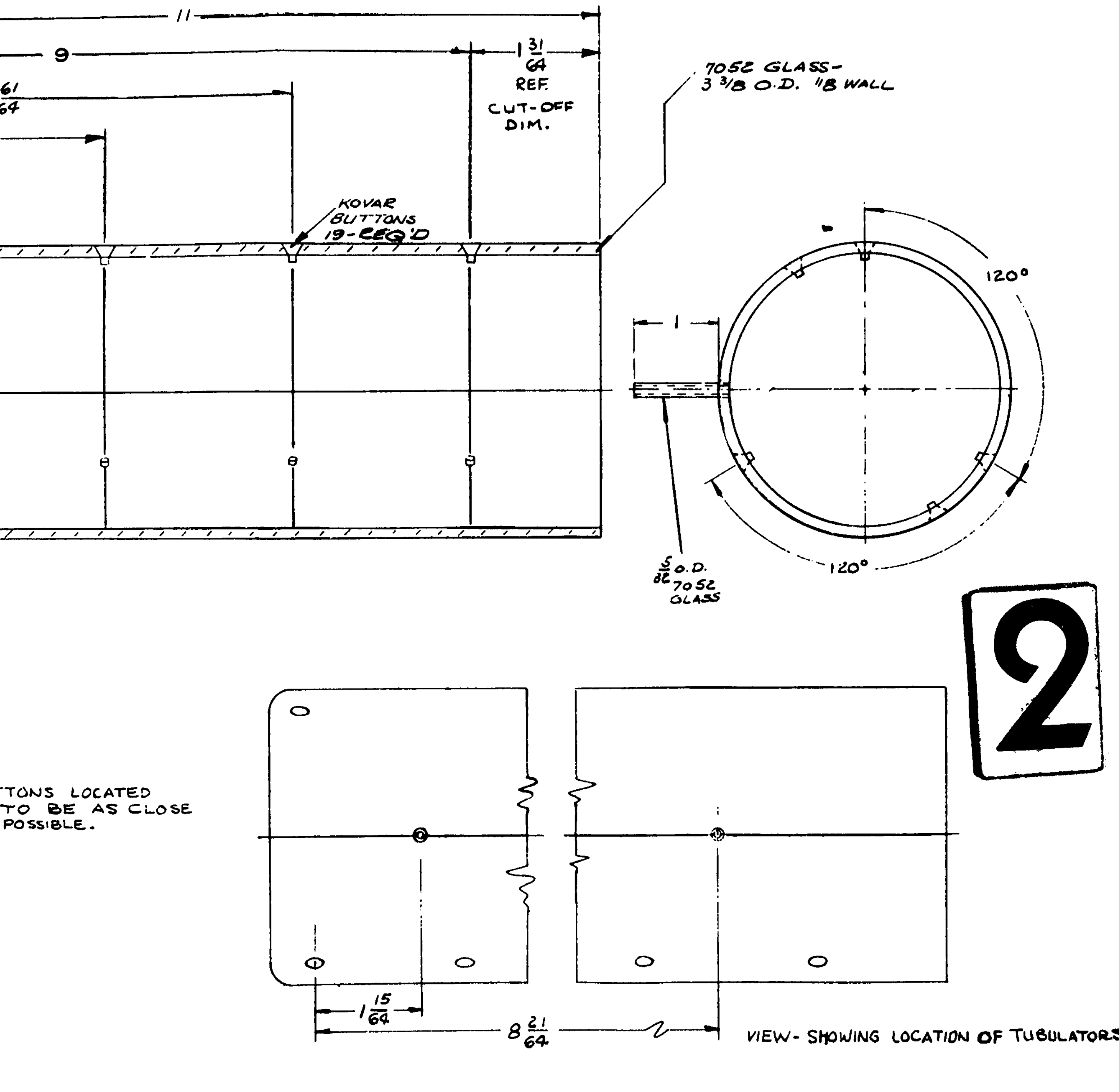
Drawing EX-21270 Mesh ring # 3


11
9
6 61/64
4 45/64
2 31/32
1 15/64
33/64
'A'
.120
7056 GLASS
1/8 R.
MAX.
INSIDE
"A"

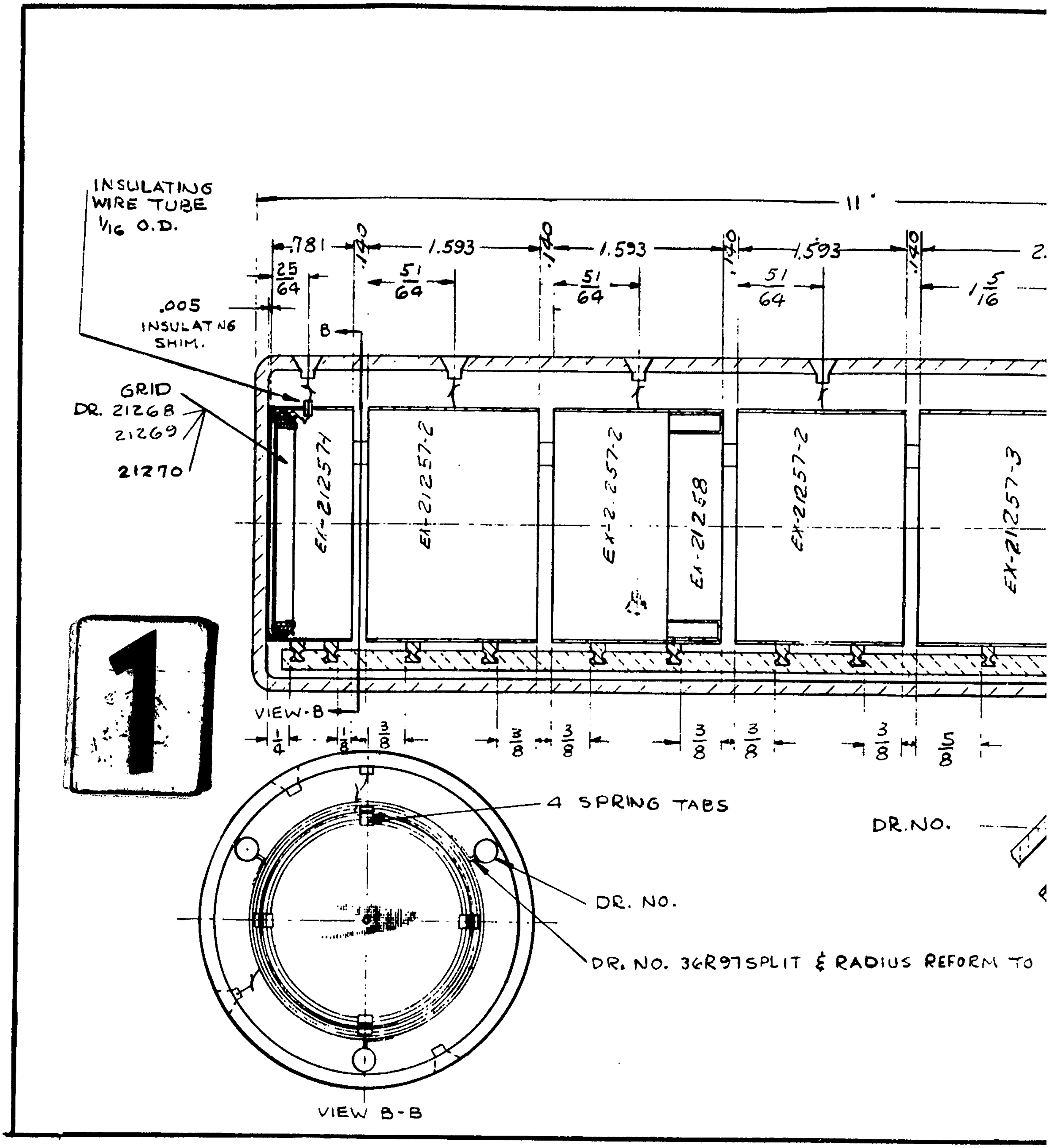

30°
90°
30°
2-KOVAR BUTTONS LOCATED
180° APART TO BE AS CLOSE
TO FACE AS POSSIBLE.

SECTION "A-A"

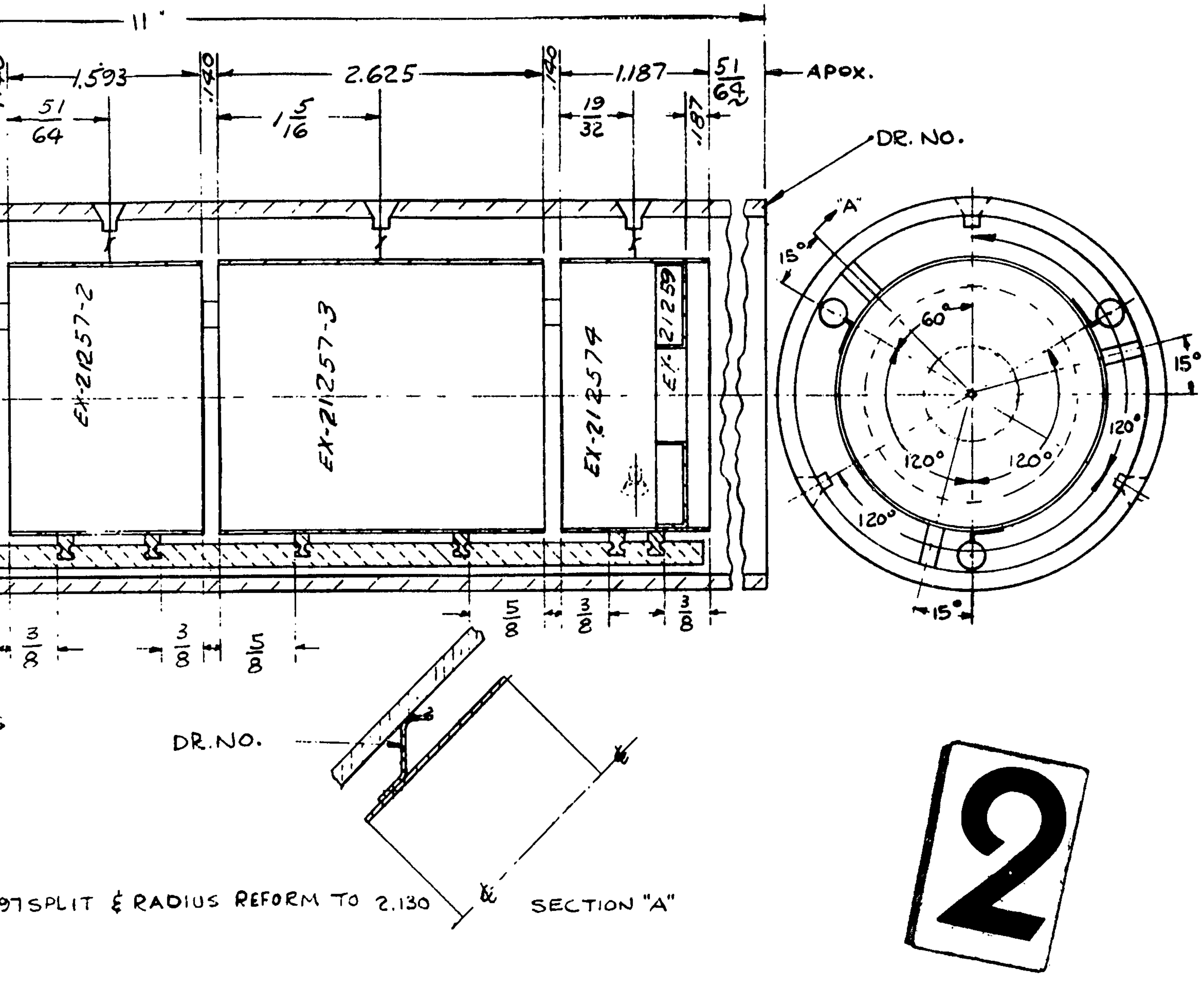




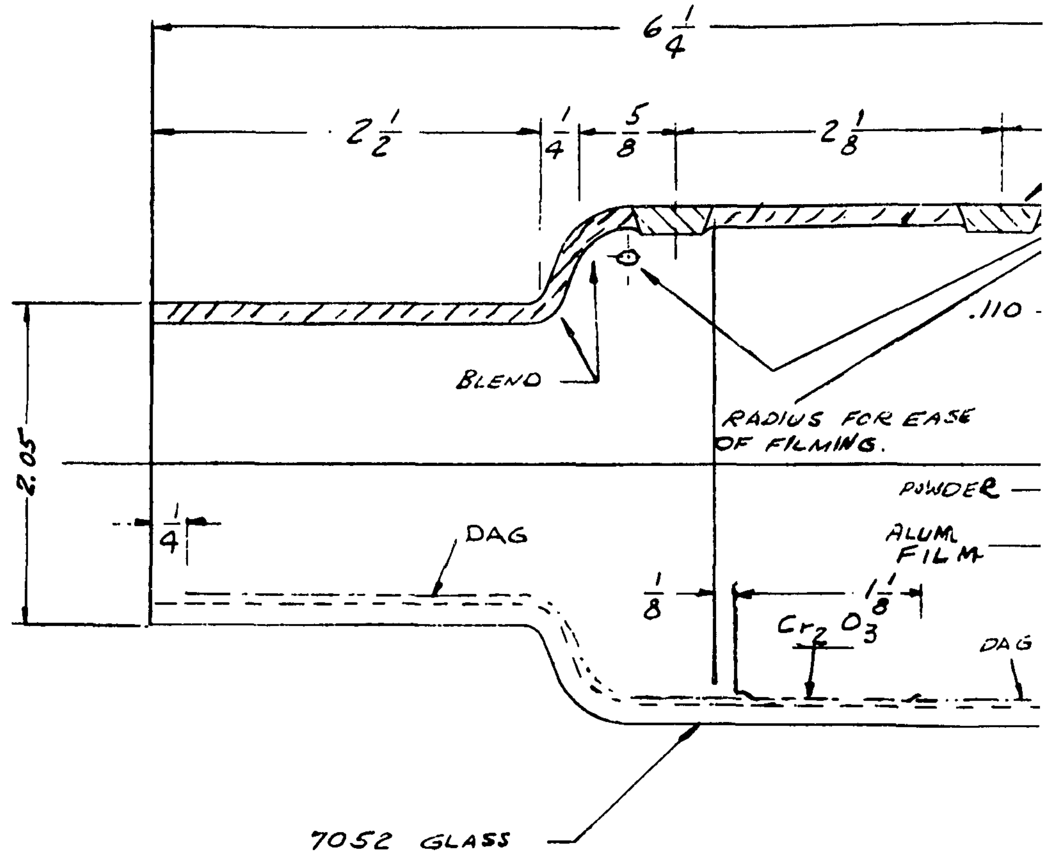
Drawing EX-21282 Focusing electrode tube

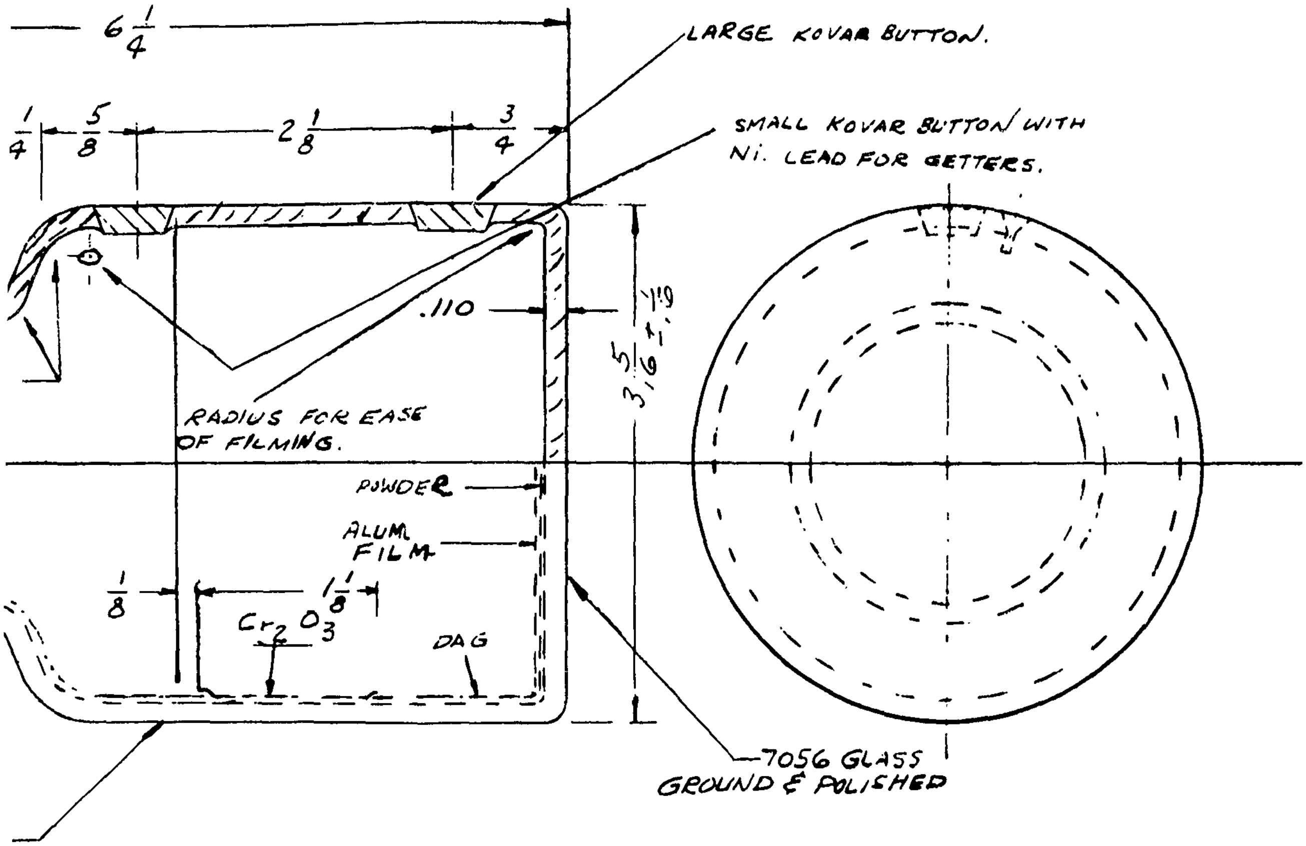


INSULATING WIRE TUBE 1/16 O.D.
11"
.781
.140
1.593
.140
1.593
.140
1.593
.140
25/64
51/64
51/64
51/64
1 5/16
.005 INSULATING SHIM.
B
GRID
DR. 21268
21269
21270
EX-21257-1
EX-21257-2
EX-21257-2
EX-21258
EX-21257-2
EX-21257-3
1
VIEW-B
1/4
1/8
3/8
3/8
3/8
3/8
3/8
3/8
5/8
4 SPRING TABS
DR.NO.
DR. NO.
DR. NO. 36R97SPLIT & RADIUS REFORM TO
VIEW B-B



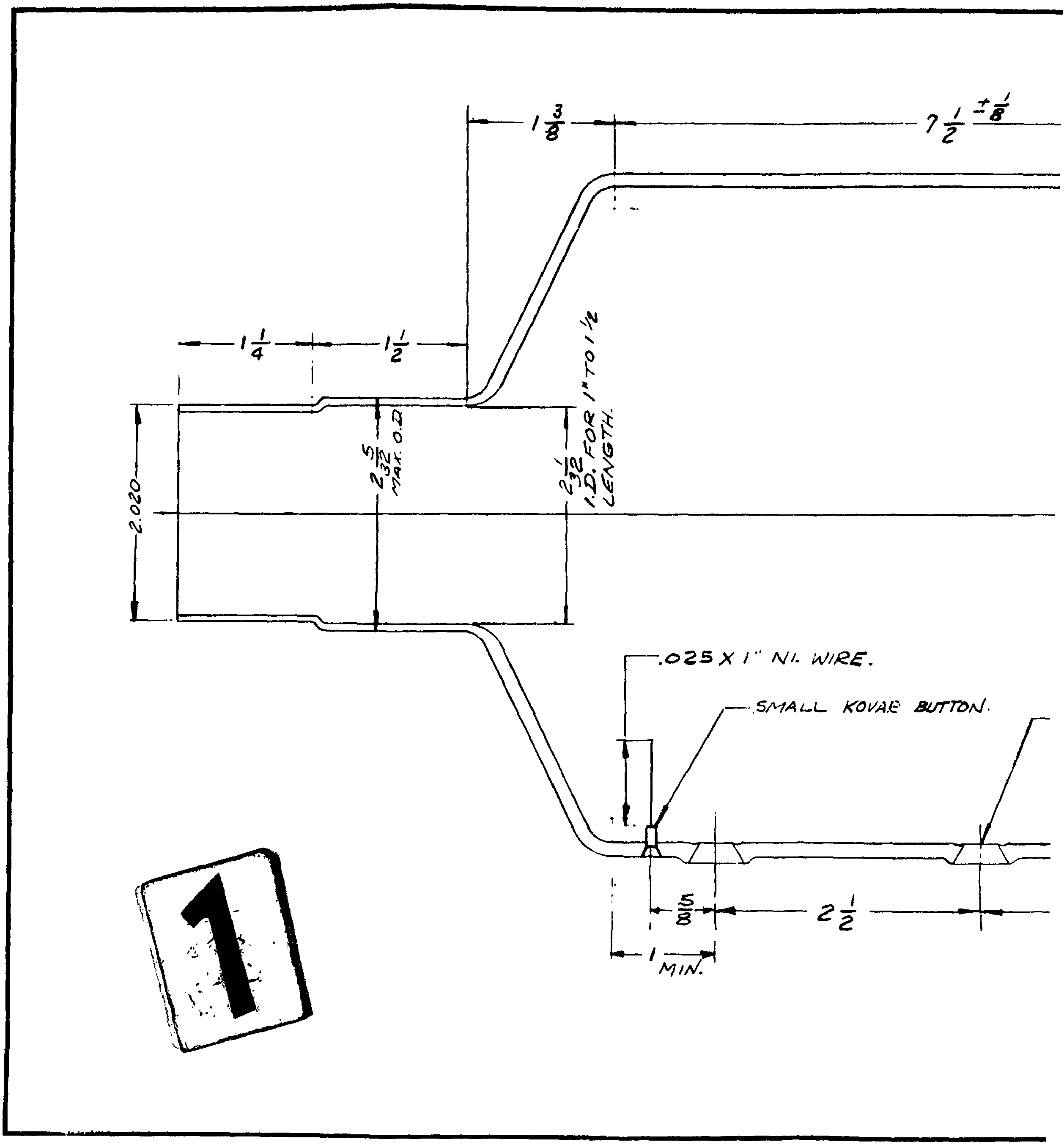
Drawing EX-21271 Complete electrode assembly


6 1/4
2 1/2
1/4
5/8
2 1/8
.110
BLEND
RADIUS FOR EASE OF FILMING.
2.05
POWDER
1/4
DAG
ALUM FILM
1/8
1 1/8
Cr2 O3
DAG
7052 GLASS

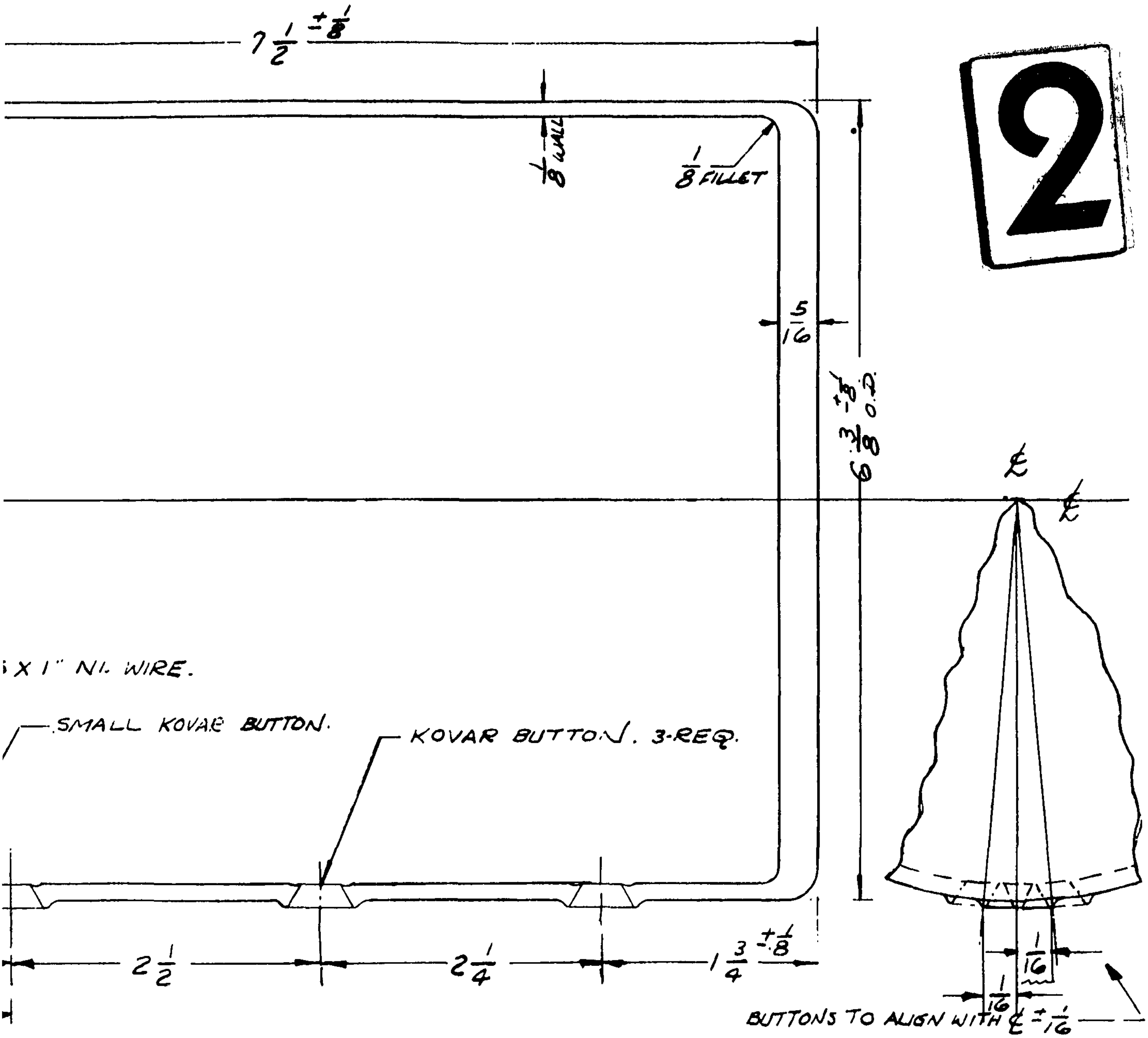


2

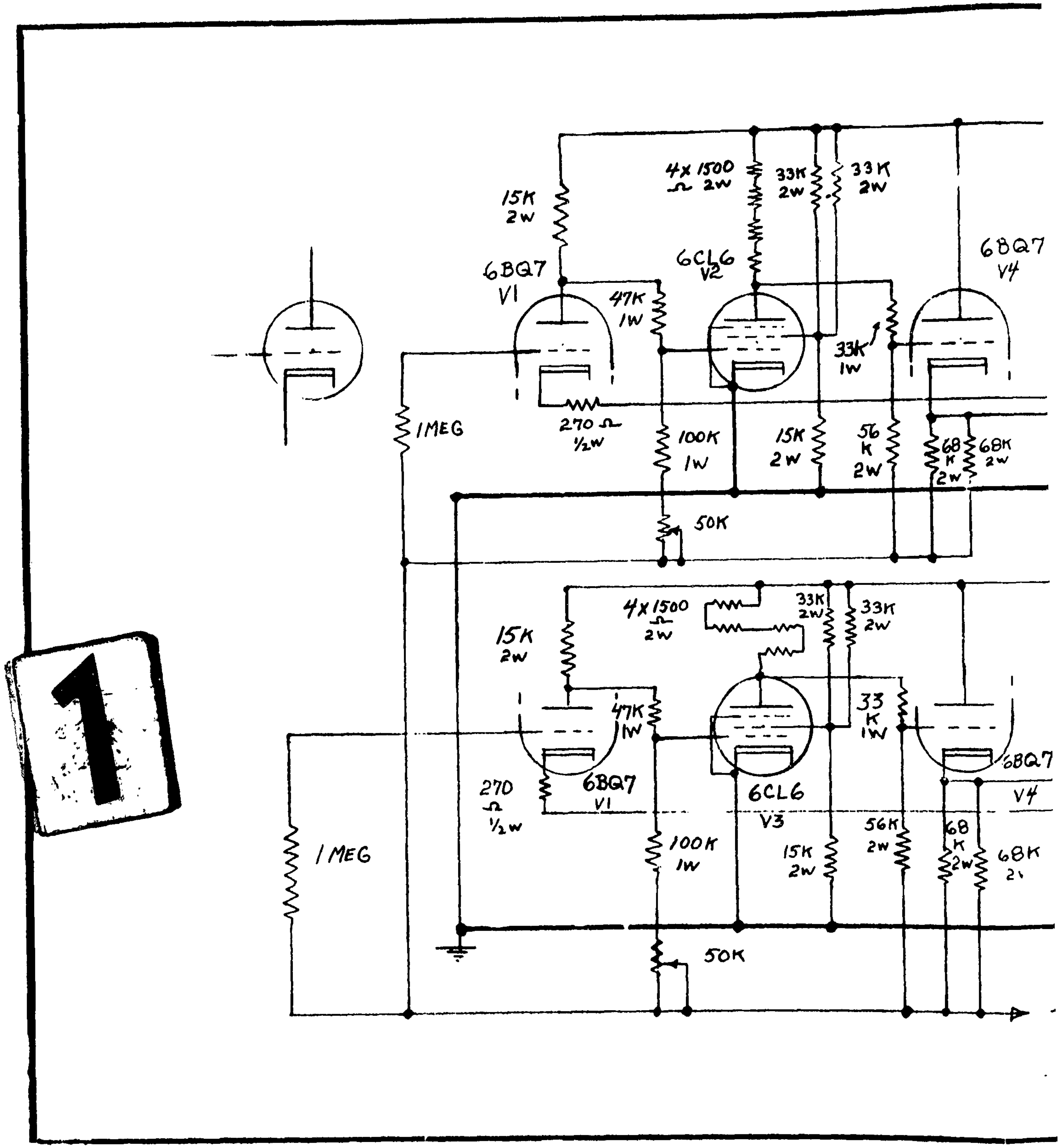
Drawing EX-21330 Screen section of envelope (small size)



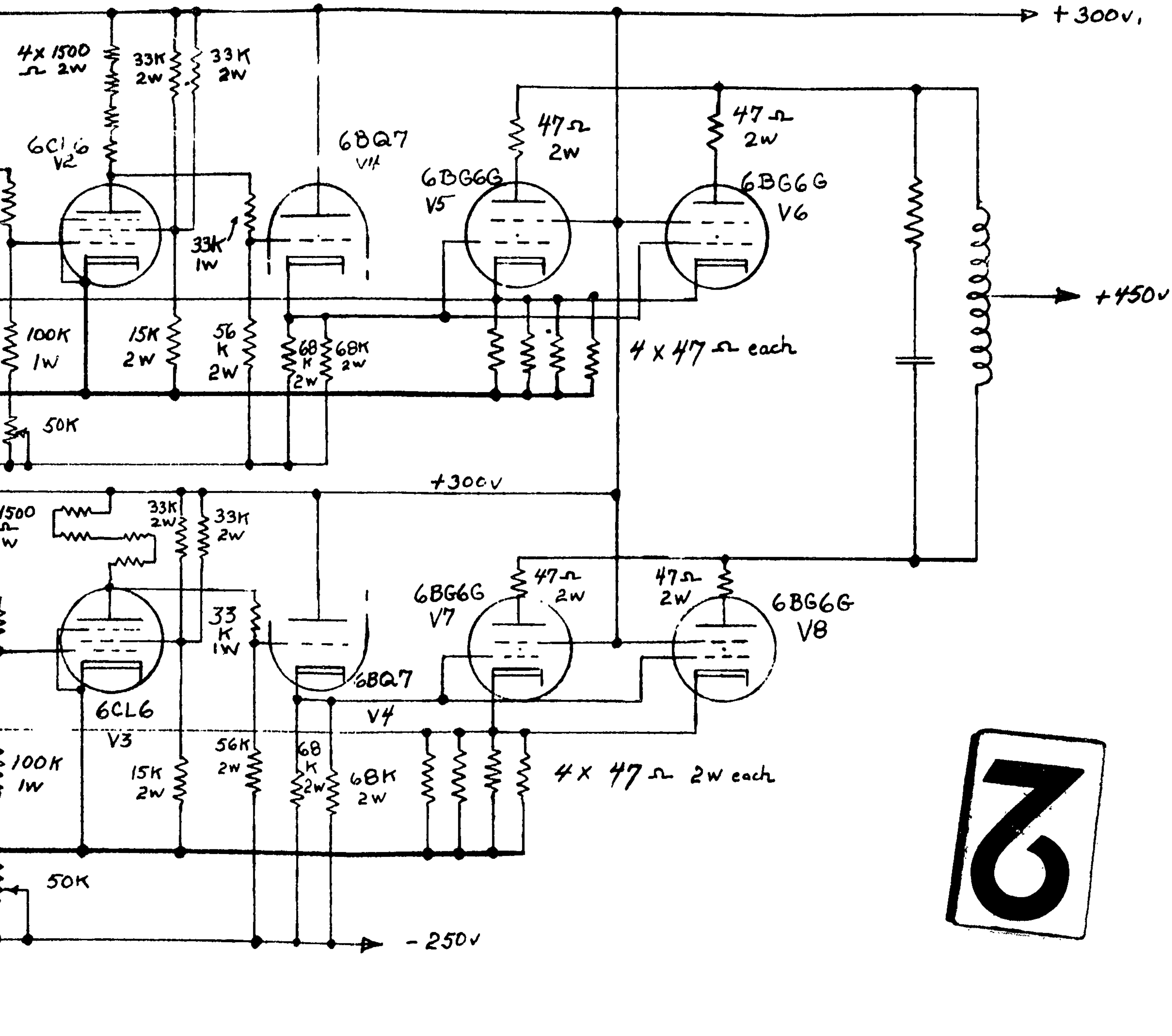
$1\frac{3}{8}$
$7\frac{1}{2} \pm\frac{1}{8}$
$1\frac{1}{4}$
$1\frac{1}{2}$
2.020
$2\frac{5}{32}$ MAX. O.D.
$2\frac{1}{32}$ I.D. FOR 1" TO 1 1/2 LENGTH.
.025 X 1" NI. WIRE.
SMALL KOVAR BUTTON.
$\frac{5}{8}$
$2\frac{1}{2}$
1 MIN.



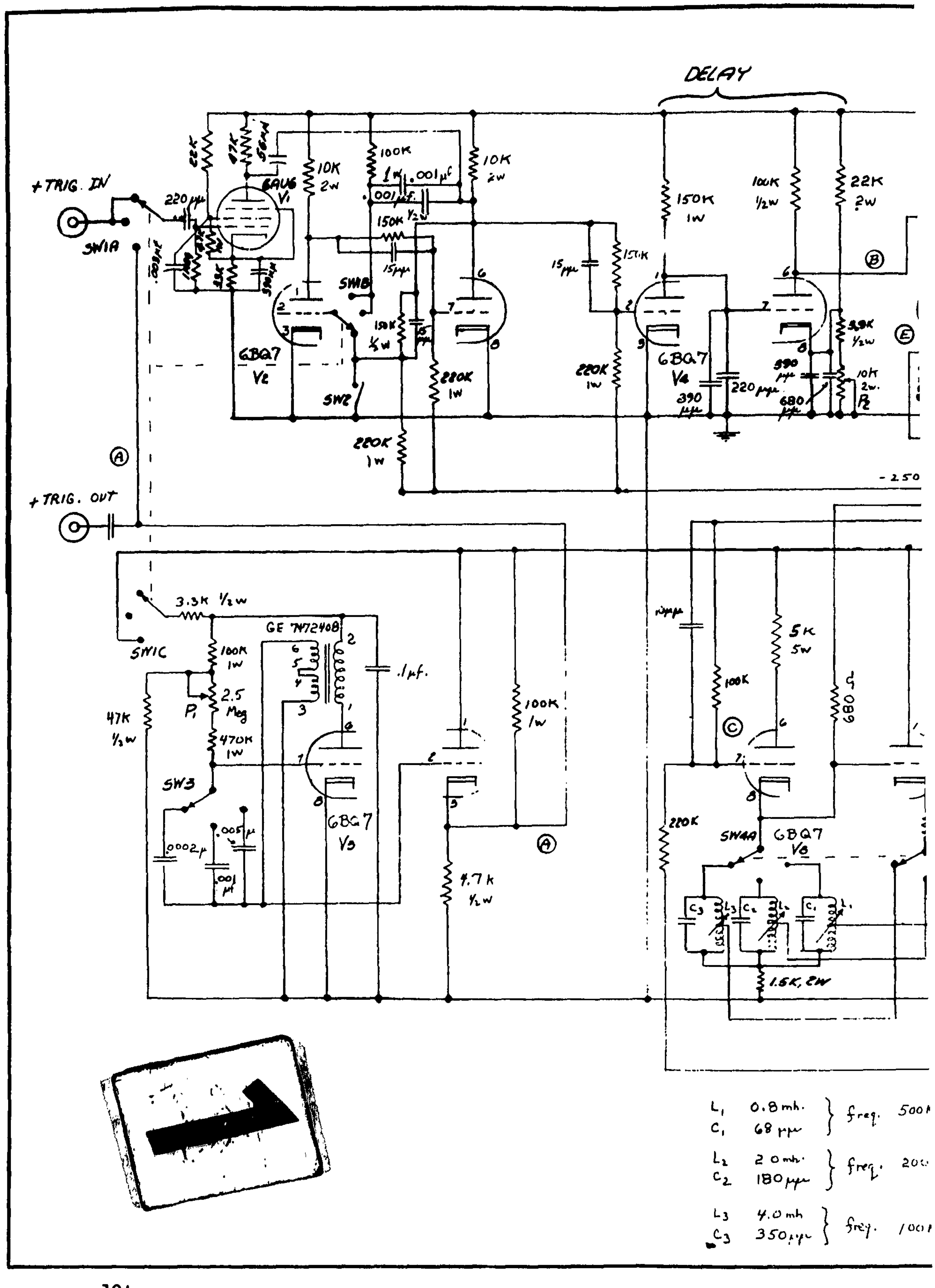
Drawing EX-21216 Screen section of envelope (large size)

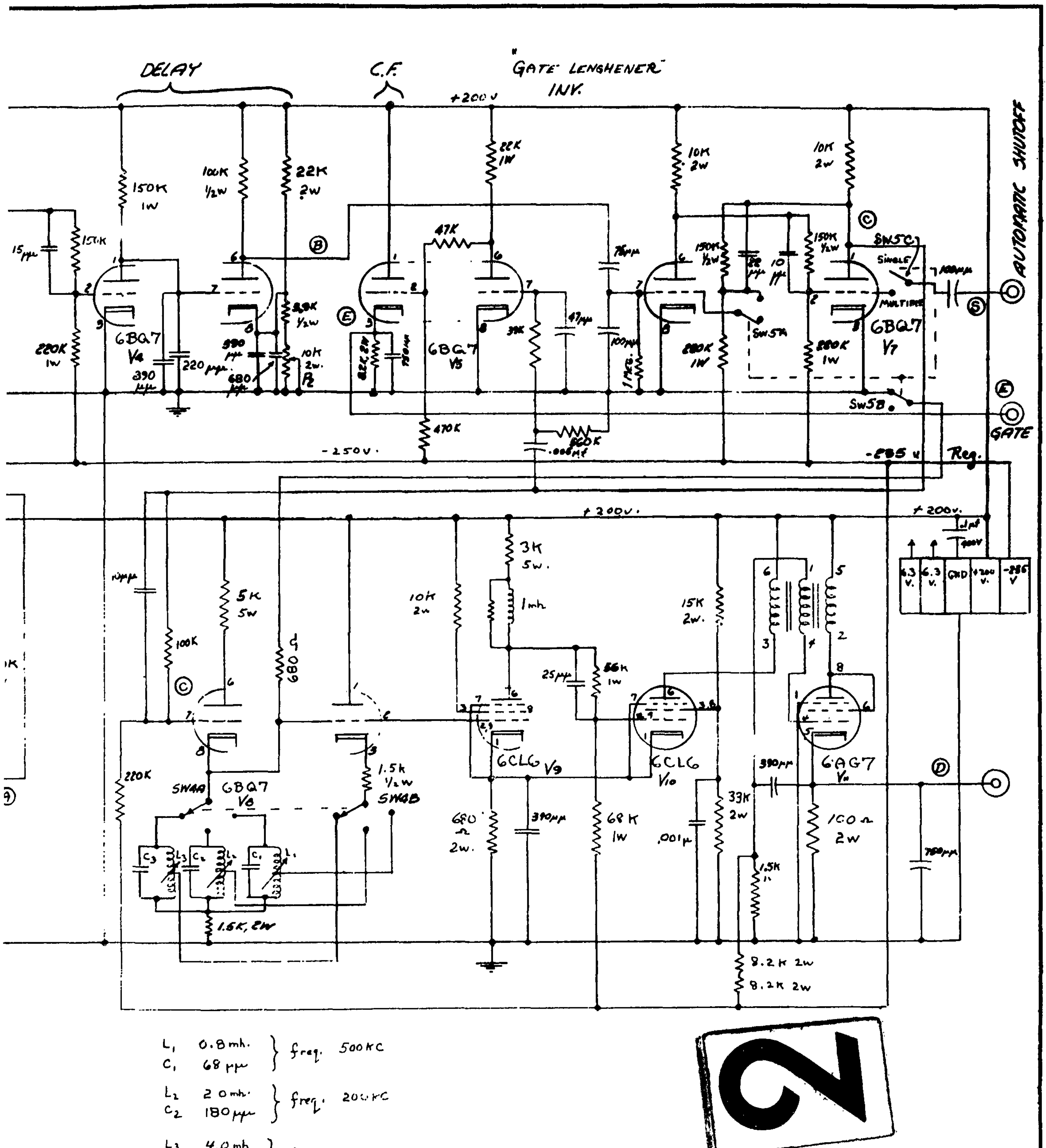


15K 2W
4x1500 Ω 2W
33K 2W
33K 2W
6BQ7 V1
6CL6 V2
6BQ7 V4
47K 1W
33K 1W
1 MEG
270 Ω ½W
100K 1W
15K 2W
56 K 2W
68 K 2W
68K 2W
50K
15K 2W
4x1500 Ω 2W
33K 2W
33K 2W
47K 1W
33 K 1W
6BQ7 V1
6CL6 V3
6BQ7 V4
270 Ω ½W
1 MEG
100K 1W
15K 2W
56K 2W
68 K 2W
68K
50K

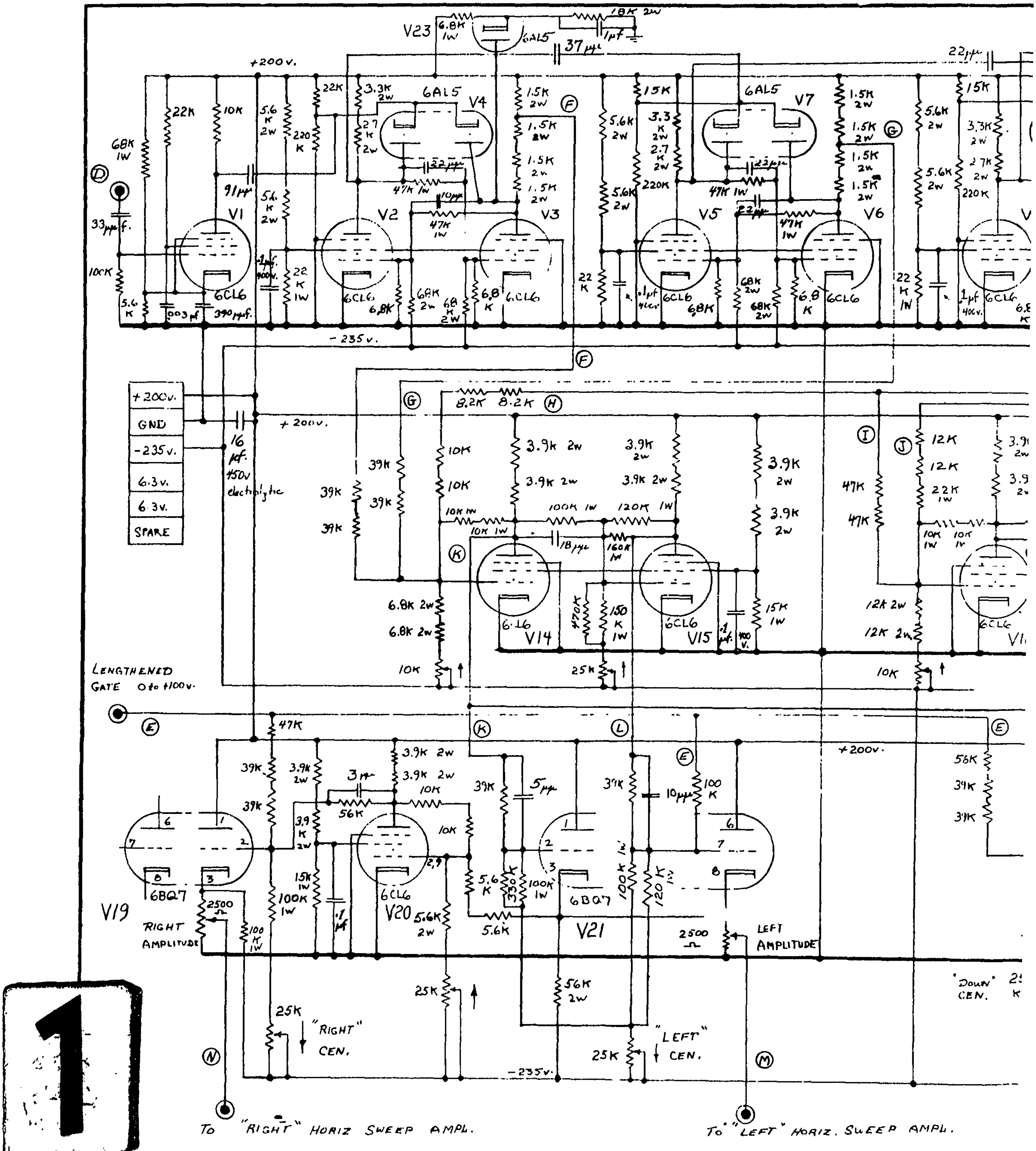


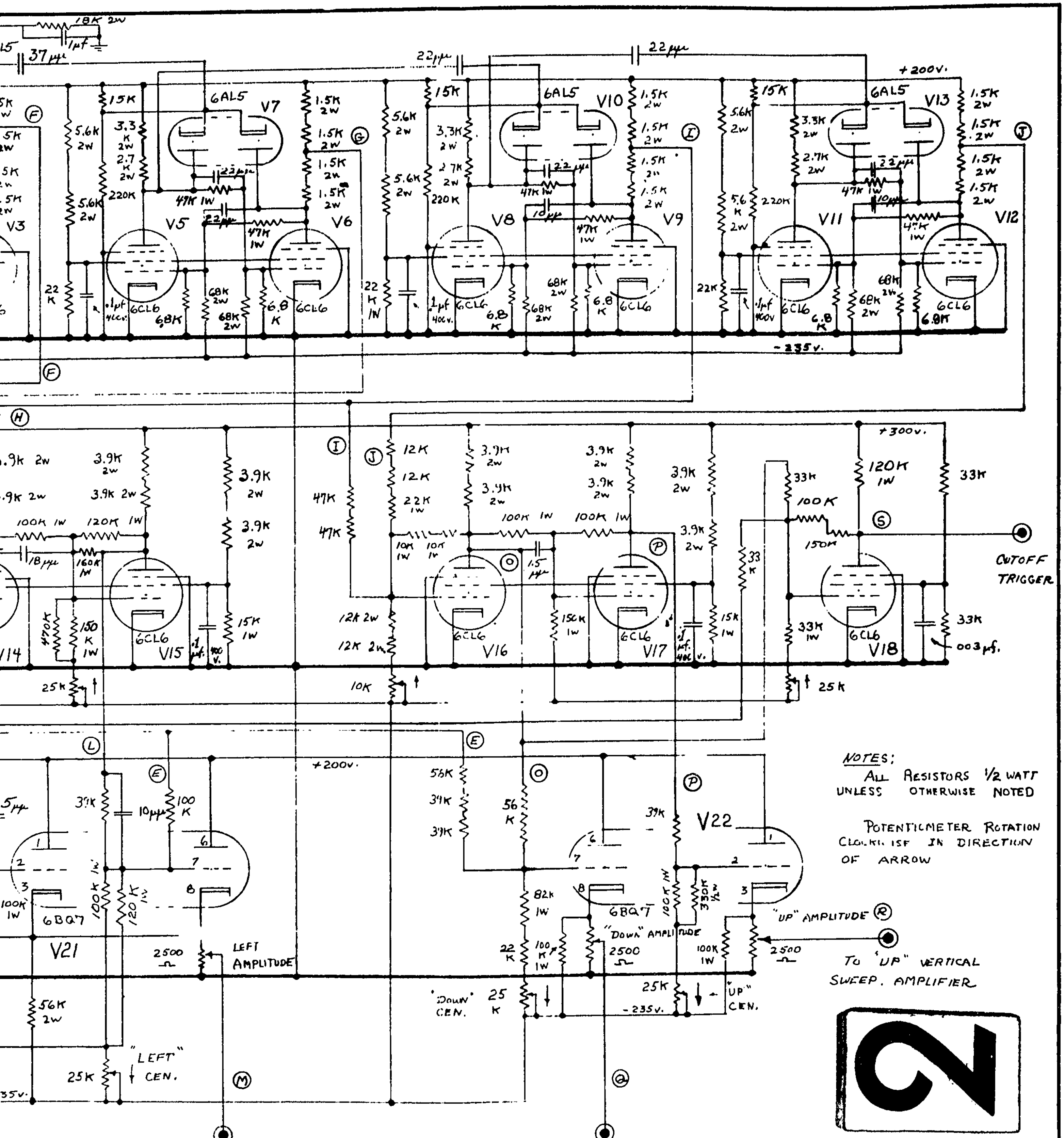
Drawing B-1219 Schematic of sweep amplifier


DELAY
+TRIG. IN
SW1A
+TRIG. OUT
6AU6
V1
6BQ7
V2
SW1B
SW2
6BQ7
V4
-250
SW1C
3.3K 1/2w
GE 7472408
.1μf.
2.5 Meg
P1
47K 1/2w
SW3
6BQ7
V3
100K 1w
4.7k 1/2w
6BQ7
V8
SW4A
5K 5w
1.5K, 2W
L1 0.8mh.
C1 68 μμ
freq. 500
L2 2.0mh.
C2 180 μμ
freq. 200
L3 4.0 mh
C3 350 μμ
freq. 100

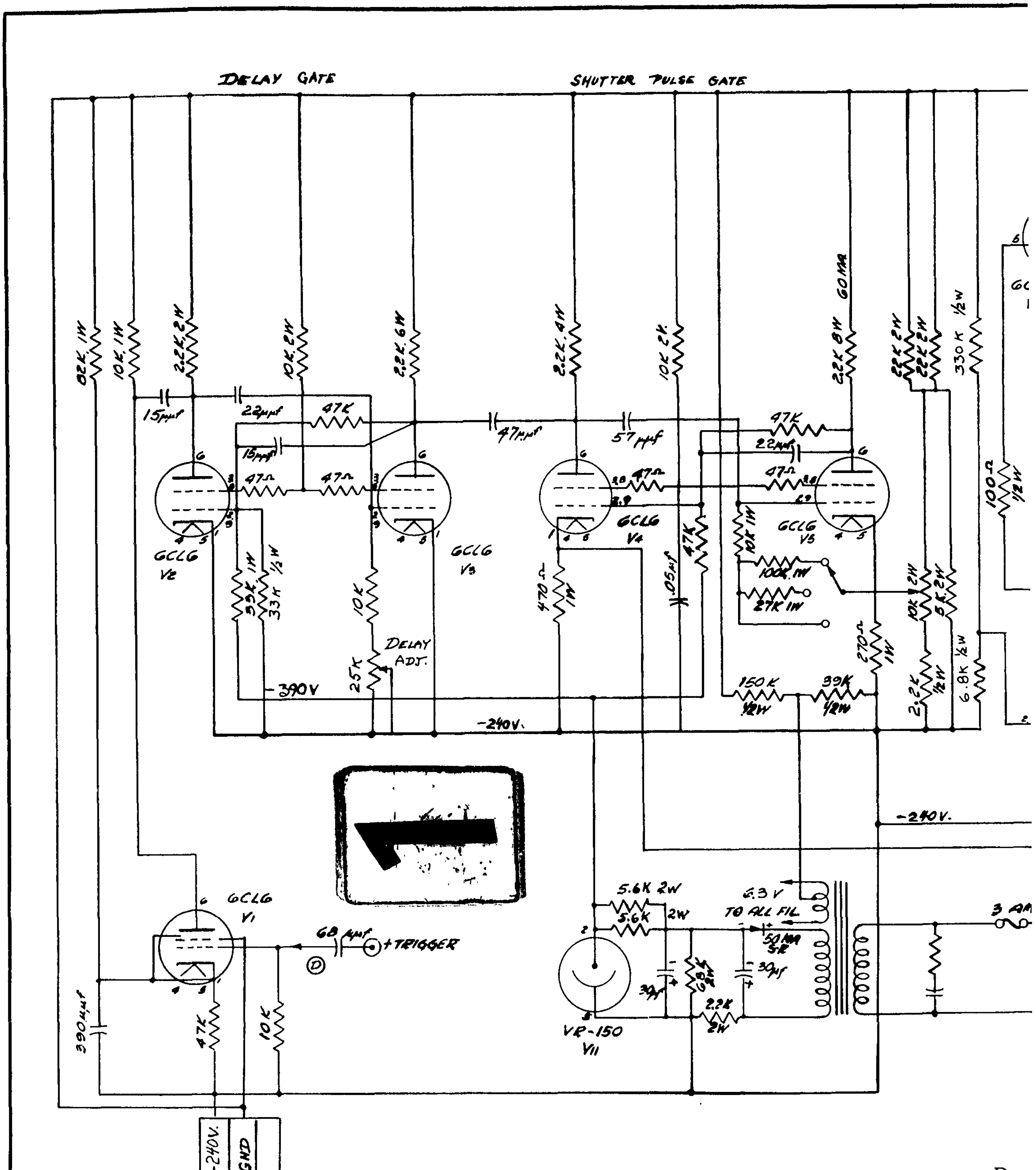


Drawing C-1037 Schematic of synchronizer

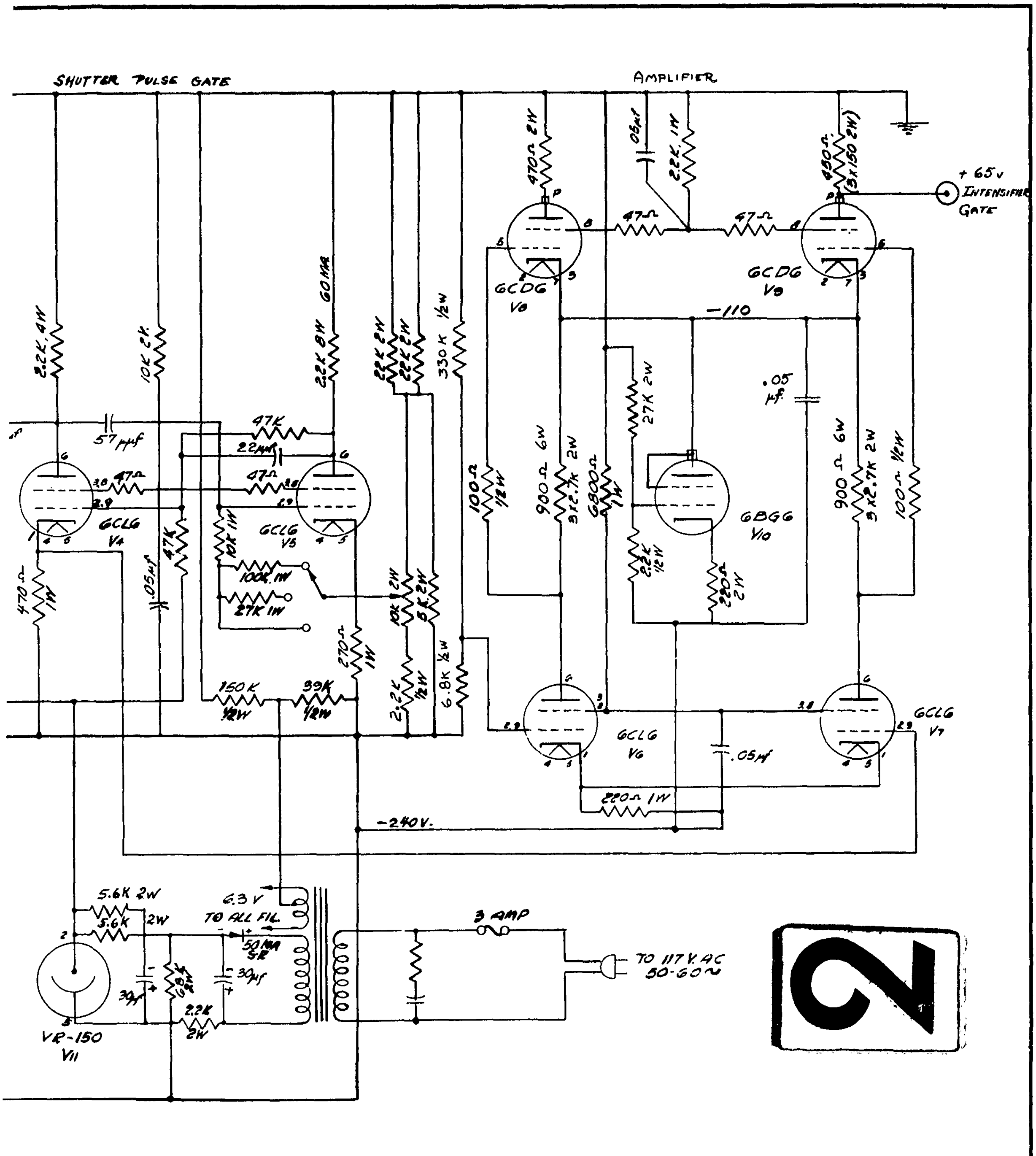

V23
6AL5
V4
V7
V1
V2
V3
V5
V6
6CL6
+200v.
-235v.
GND
6.3v.
SPARE
16 μf. 450v electrolytic
LENGTHENED GATE 0 to +100v.
V14
V15
6BQ7
V19
V20
V21
RIGHT AMPLITUDE
LEFT AMPLITUDE
"RIGHT" CEN.
"LEFT" CEN.
"DOWN" CEN.
To "RIGHT" HORIZ SWEEP AMPL.
To "LEFT" HORIZ. SWEEP AMPL.



Drawing C-1357 Schematic of shaper


DELAY GATE
SHUTTER PULSE GATE
6CL6
V2
6CL6
V3
6CL6
V4
6CL6
V5
6CL6
V1
DELAY ADJ.
-390V
-240V.
+TRIGGER
6.3 V
TO ALL FIL
VR-150
V11
-240V.
GND

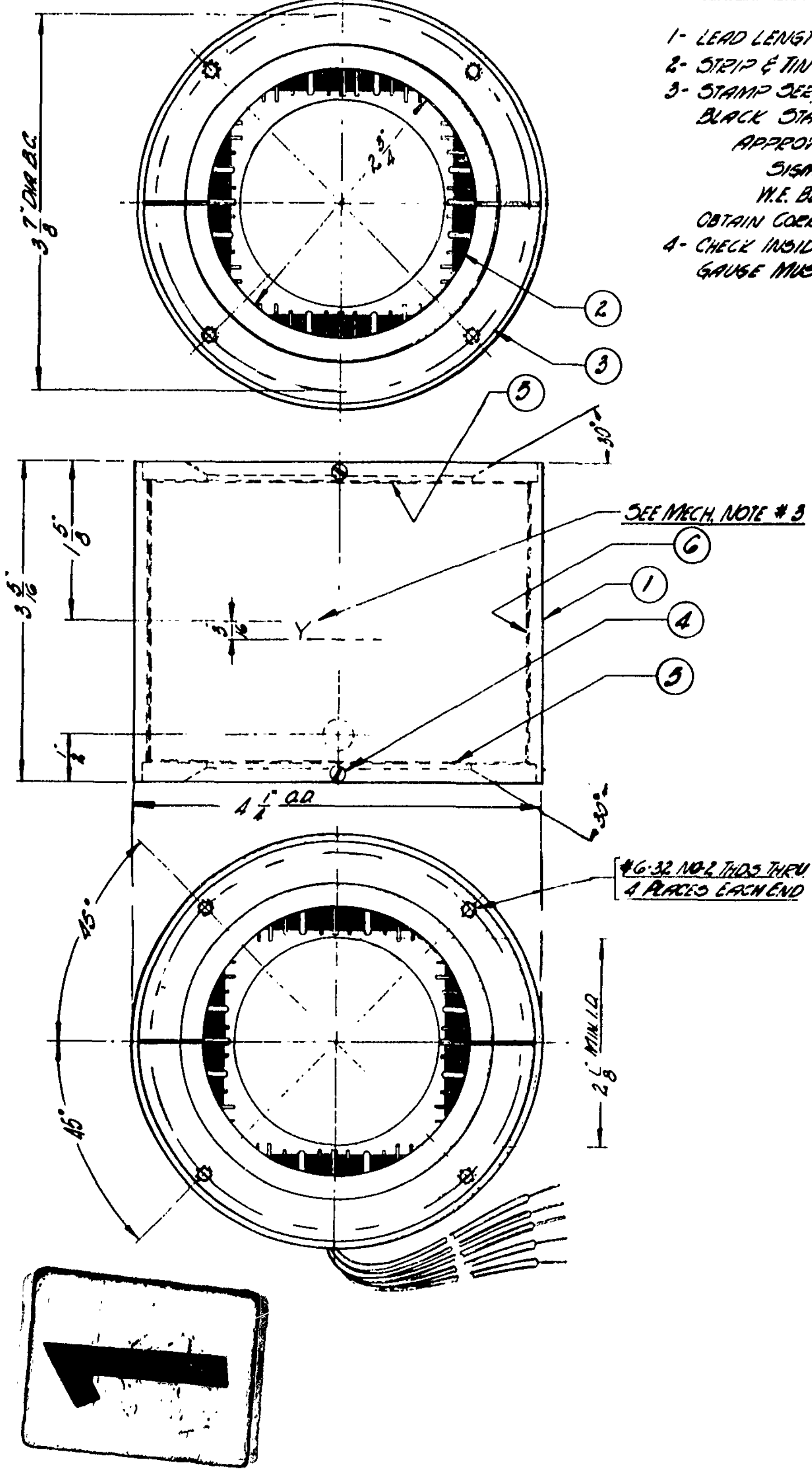
Dra



Drawing C-1229 Schematic of shutter pulse generator

MECHANICAL SPECIFICATIONS

1- LEAD LENGTH TO BE 24½" ± ½" FROM OUTLET OF CAS
2- STRIP & TIN ALL LEADS 5/16" ± 1/16"
3- STAMP SERIAL Nº IN POSITION INDICATED WIT
BLACK STAMPING INK.
APPROVED INK SUPPLIER
SISMUN ULLMAN CO.
W.E. BLACK #Q.D. 45 SPEC. #11379 OR EQUIV.
OBTAIN CORRECT SERIAL Nº FROM PRODUCTION OF
4- CHECK INSIDE DIA. (2⅛") WITH PLUG GAUGE #B150
GAUGE MUST FALL THRU OF ITS OWN WEIGHT.



C1688

MECHANICAL SPECIFICATIONS

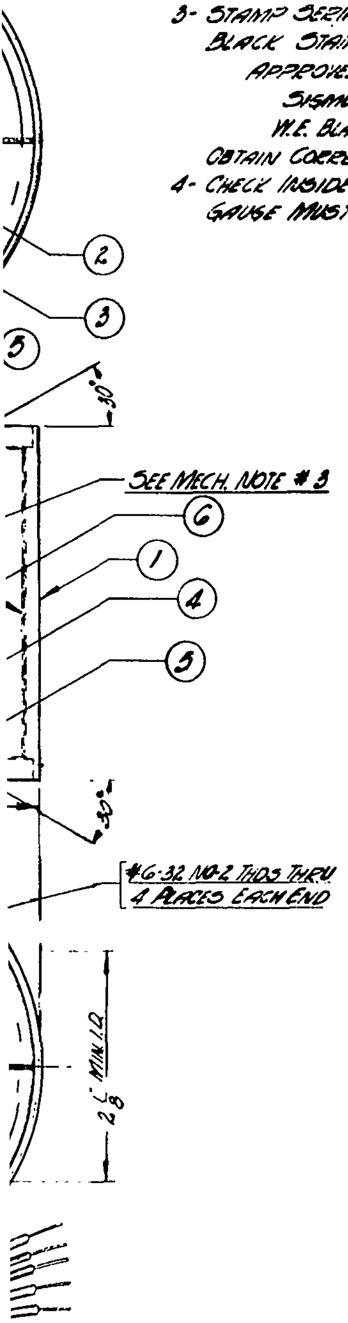
1- LEAD LENGTH TO BE 24 1/2" ± 1/2" FROM OUTLET OF CASE.
2- STRIP & TIN ALL LEADS 1/16" ± 1/16"
3- STAMP SERIAL Nº IN POSITION INDICATED WITH BLACK STAMPING INK.
   APPROVED INK SUPPLIER
   SIGMUND ULLMAN CO.
   W.E. BLACK #Q.D.45 SPEC. #11379 OR EQUIV.
   OBTAIN CORRECT SERIAL Nº FROM PRODUCTION ORDER.
4- CHECK INSIDE DIA. (2 1/8") WITH PLUG GAUGE #B1507-3 GAUGE MUST FALL THRU OF ITS OWN WEIGHT.

ELECTRICAL SPECIFICATIONS

1- VOLTAGE BREAK DOWN: 5000 VDC 1 MINUTE MIN. COILS TO CORE. LEAKAGE CURRENT SHOULD NOT EXCEED 4 μa DURING THIS TEST.
2- INDUCED VOLTAGE: THE INSULATION OF THE WINDINGS SHALL BE CAPABLE OF WITHSTANDING A PEAK VOLTAGE OF 3500 V IMPRESSED BETWEEN B+ AND PLATE LEAD OF ANY WINDING FOR A PERIOD OF ONE MINUTE MIN. THE WAVEFORM & DUTY RATIO SHALL BE SUCH THAT THE COIL DOES NOT OVERHEAT.
3- ELECTRICAL CHARACTERISTICS

LEAD	FUNCTION	R	L
BLUE	RIGHT	3.5 Ω	7 mh
GREEN	UP	±10%	±5%
RED	LEFT	EACH	EACH
YELLOW	DOWN	COIL	COIL
BLACK-RED	B+(COMMON)	TO B+	TO B+

4- RESONANT FREQUENCY: THE RESONANT FREQUENCY OF THE UNDAMPED YOKE SHALL BE 600,000 C.P.S.
5- RESOLUTION: THE RESOLUTION SHALL BE LESS THAN ONE WHEN MEASURED PER SYNTRONIC INST. SPEC. #B1545
6- POLARITY: DIRECTION OF SPOT DEFLECTION SHALL BE AS INDICATED IN NOTE #4 WITH YOKE LEAD HOLE IN DOWNWARD POSITION & OPERATOR FACING C.R. TUBE.
7- THE ORTHOGONALITY SHALL BE WITHIN ± 30'.
8- CROSS TALK SHALL BE 40 DB MIN. AS MEASURED PER SYNTRONIC INST. SPEC. #B1546

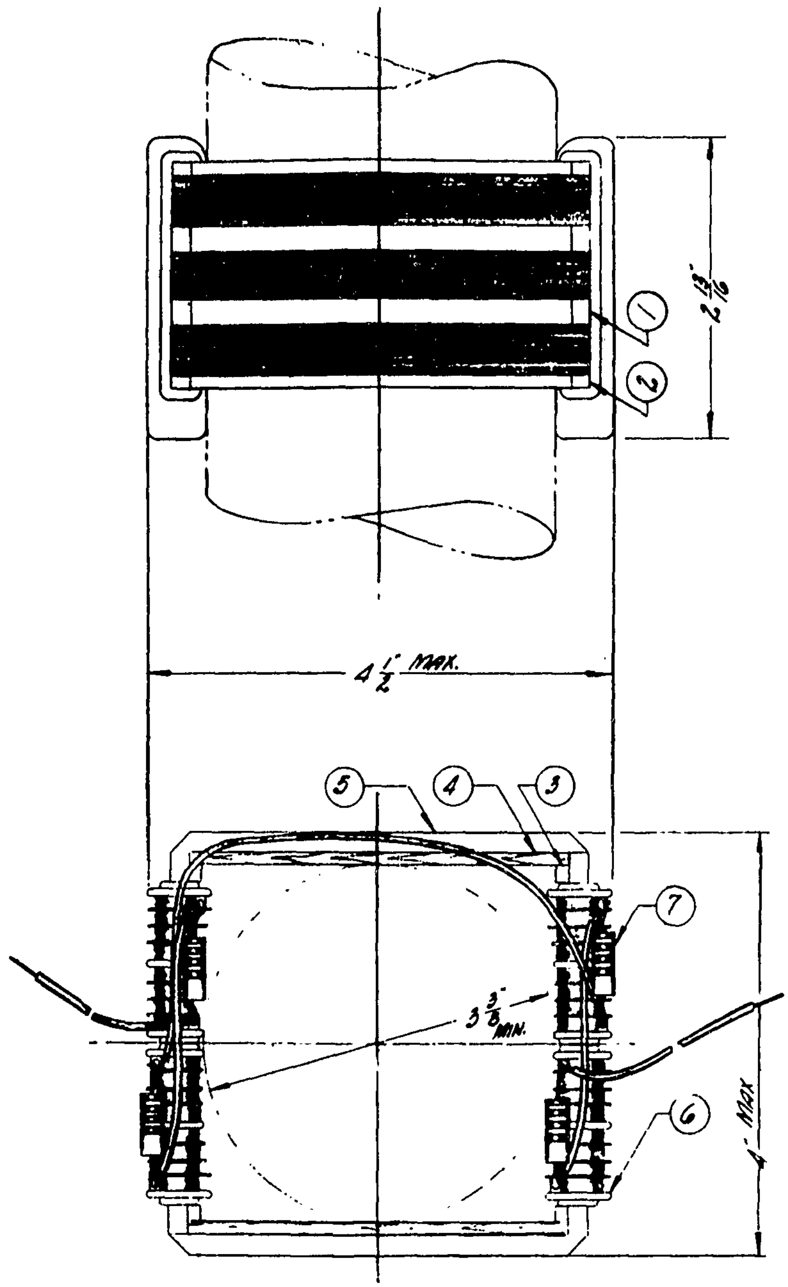


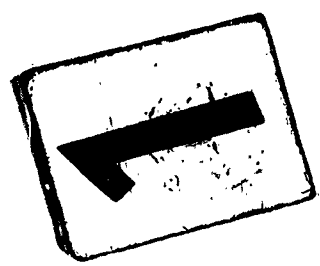
PART Nº	ITEM	REQ.	DESCRIPTION
	6	[illegible] EA.	GLASTIC .015" THK. 2 WRAPS
A1717-1	5	2	SPACER
25642M211	4	12	SCREW, F.H.M.
A1555-1	3	4	END PLATE
C1523-1	2	1	ASSEM. COIL
A1556	1	1	CASE

Drawing C-1688 Deflection yoke

MECHANICAL SPECIFICATIONS

1- LEAD LENGTH TO BE 24 1/2" ± 1/2"
2- STRIP & TIN ALL LEADS 5/16" ± 1/16"





MECHANICAL SPECIFICATIONS

1- LEAD LENGTH TO BE 24 1/2" ± 1/2"
2- STRIP & TIN ALL LEADS 3/16" ± 1/16"

ELECTRICAL SPECIFICATIONS

1- DAMPING RESIS. 10K 1W ±10%
2- VOLTAGE BREAK DOWN: 5000 VDC 1 MINUTE MIN. COILS TO CORE. LEAKAGE CURRENT SHOULD NOT EXCEED 4 μa DURING THIS TEST.
3- INDUCED VOLTAGE: THE INSULATION OF THE WINDINGS SHALL BE CAPABLE OF WITHSTANDING A PEAK VOLTAGE OF 3500 V IMPRESSED BETWEEN B+ AND PLATE LEAD OF ANY WINDING FOR A PERIOD OF ONE MINUTE MIN. THE THE WAVEFORM & DUTY RATIO SHALL BE SUCH THAT THE COIL DOES NOT OVERHEAT.
4- ELECTRICAL CHARACTERISTICS

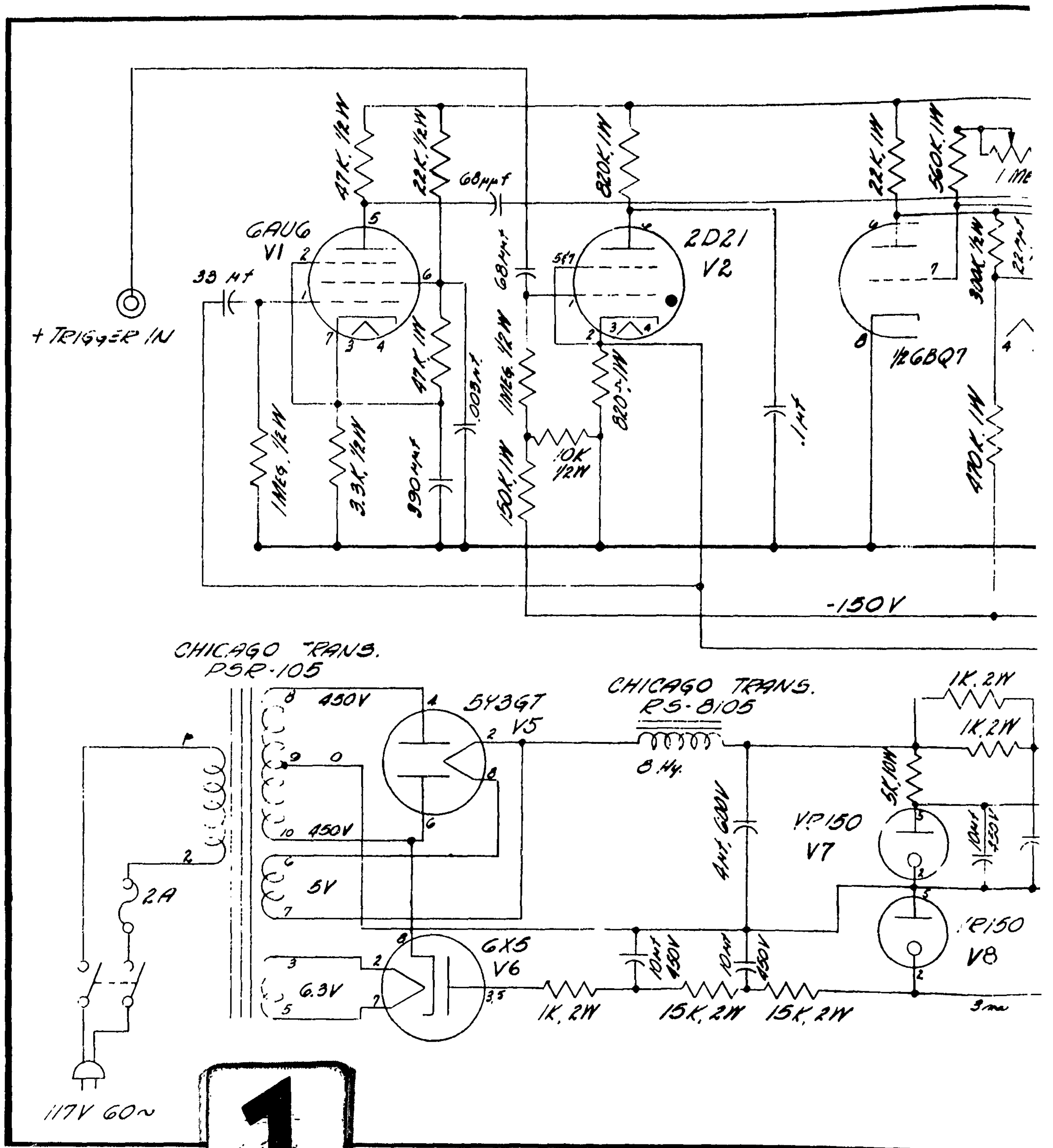
LEAD	FUNCTION	R	L	SENSITIVITY (26° @ 12 KV)
BLUE-RED	RIGHT-LEFT	94.0 Ω ±10%	210 mh ±5%	194 ma

5- RESONANT FREQUENCY: THE RESONANT FREQUENCY OF THE UNDAMPED YOKE SHALL BE 46,000 C.P.S. MIN
6- RESOLUTION: THE RESOLUTION SHALL BE LESS THAN 2 WHEN MEASURED PER SYNTRONIC INST. SPEC. #B1546

2

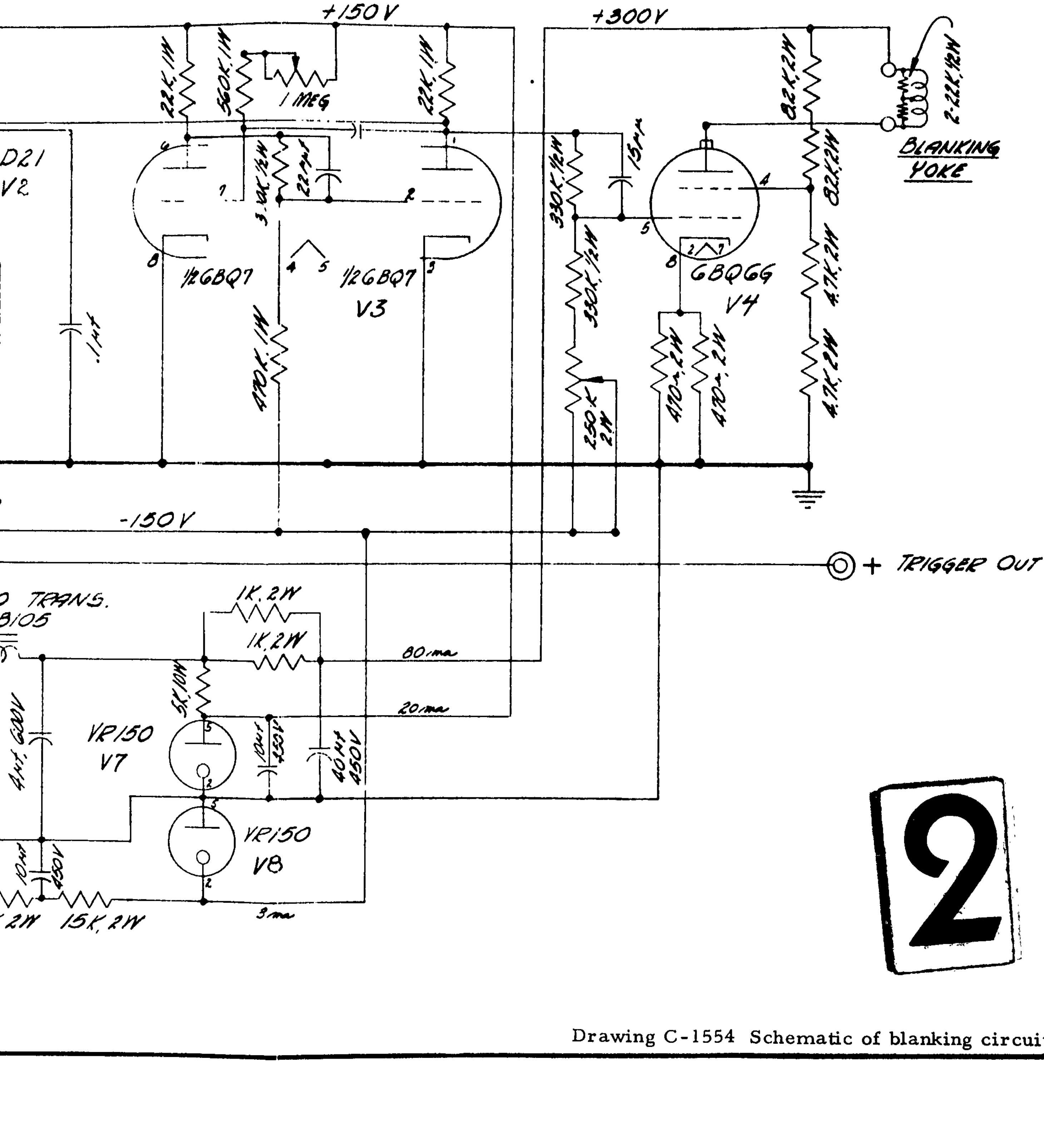
PART NO	ITEM	REQ.	DESCRIPTION
	7	4	RESISTOR 10K. 1W. ±10%
B1476	6	4	BOBBIN
A1653	5	180	LAMINATION
	4	2	SPACER, 2 1/8" X 5/32" X 3.6" GLASTIC
	3	4	SPACER, 7/32" X 1/8" X 2 1/8" BAKELITE
	2	4	SPACER 1/8" X 1/8" X 3" BAKELITE
	1	4	SPACER, 1/8" X 1/4" X 3" BAKELITE

Drawing C-1687 Blanking yoke

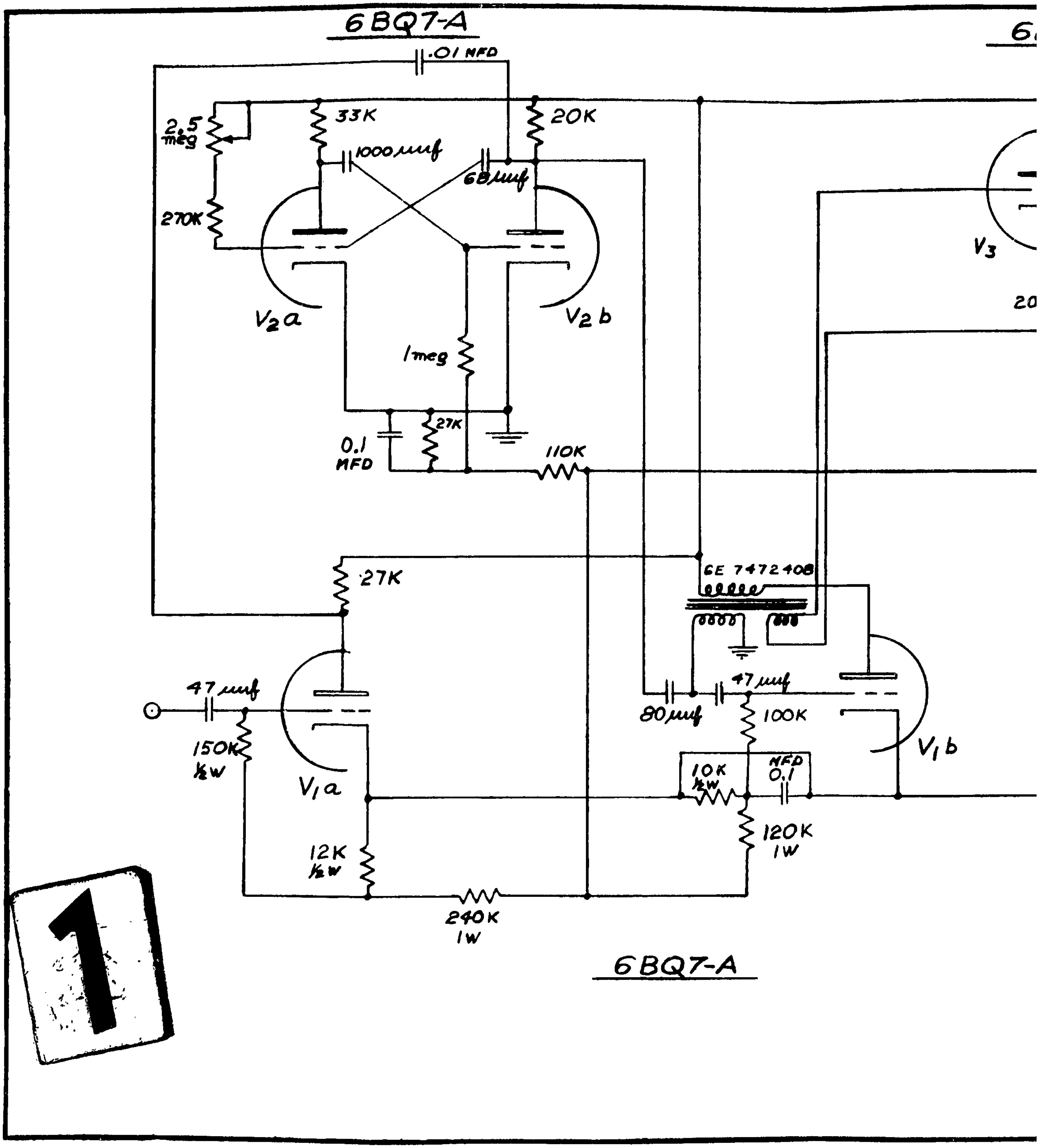


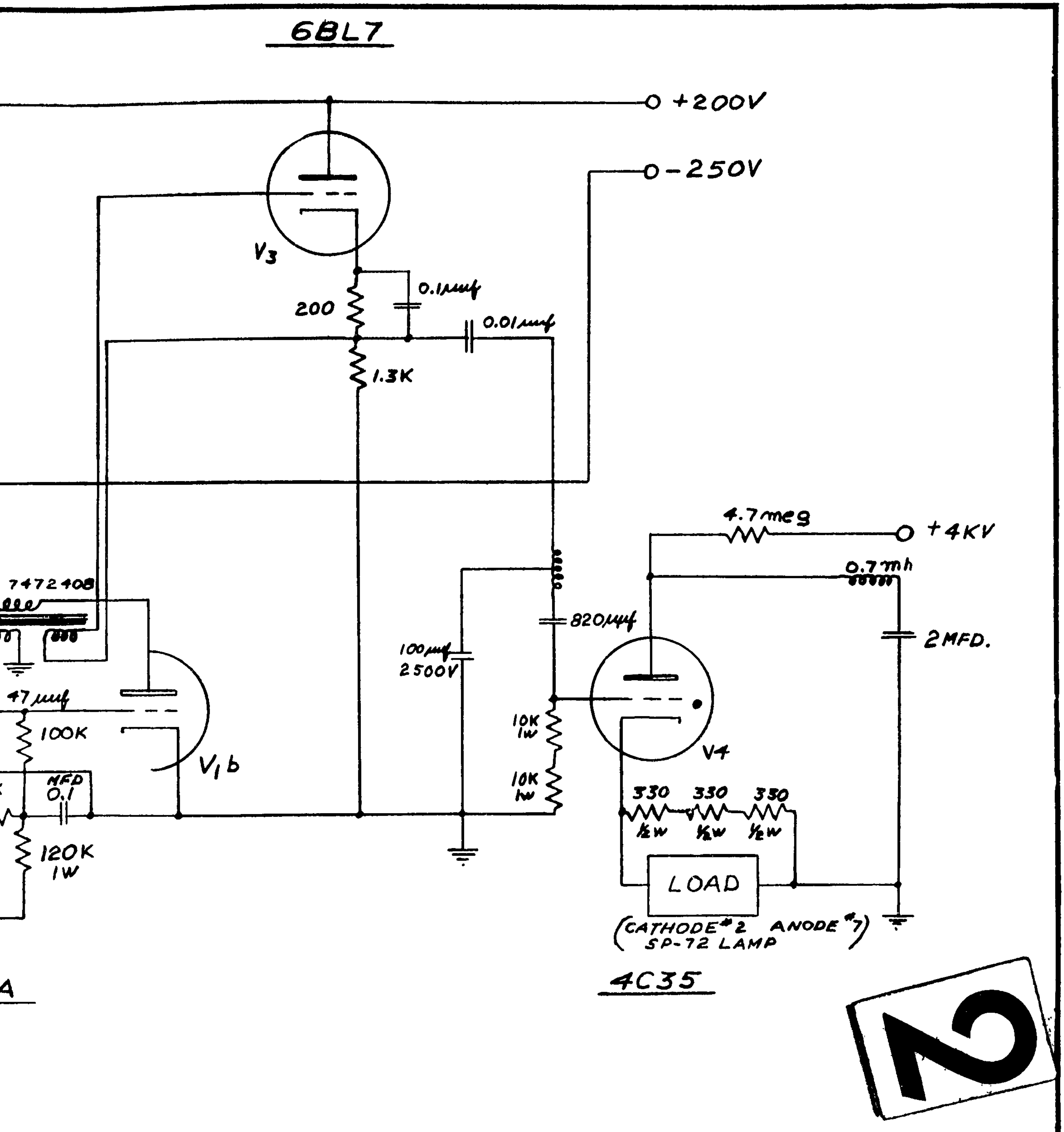
+TRIGGER IN
33 μf
6AU6
V1
47K 1/2W
22K 1/2W
68μμf
47K 1W
.003μf
390μμf
1MEG. 1/2W
3.3K 1/2W
820K 1W
2D21
V2
68μμf
1MEG. 1/2W
820Ω 1W
10K 1/2W
150K 1W
.1μf
22K 1W
560K 1W
1/2 6BQ7
470K 1W
-150V
CHICAGO TRANS.
PSR-105
450V
450V
5V
6.3V
2A
117V 60~
5Y3GT
V5
6X5
V6
CHICAGO TRANS.
RS-8105
8 Hy.
4μf, 600V
10μf 450V
10μf 450V
1K, 2W
15K, 2W
15K, 2W
1K, 2W
1K, 2W
5K, 10W
VR150
V7
VR150
V8
10μf 450V

1

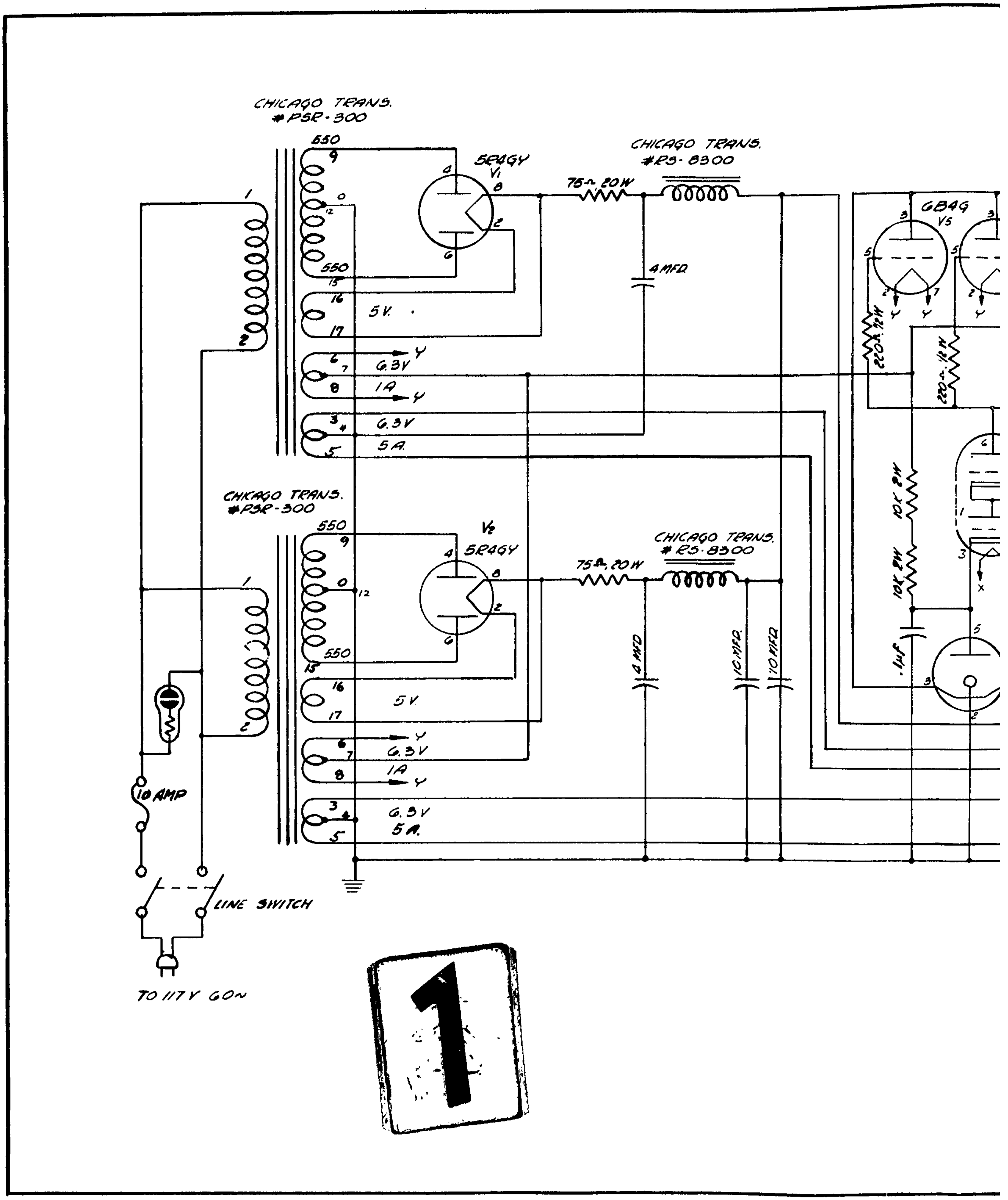


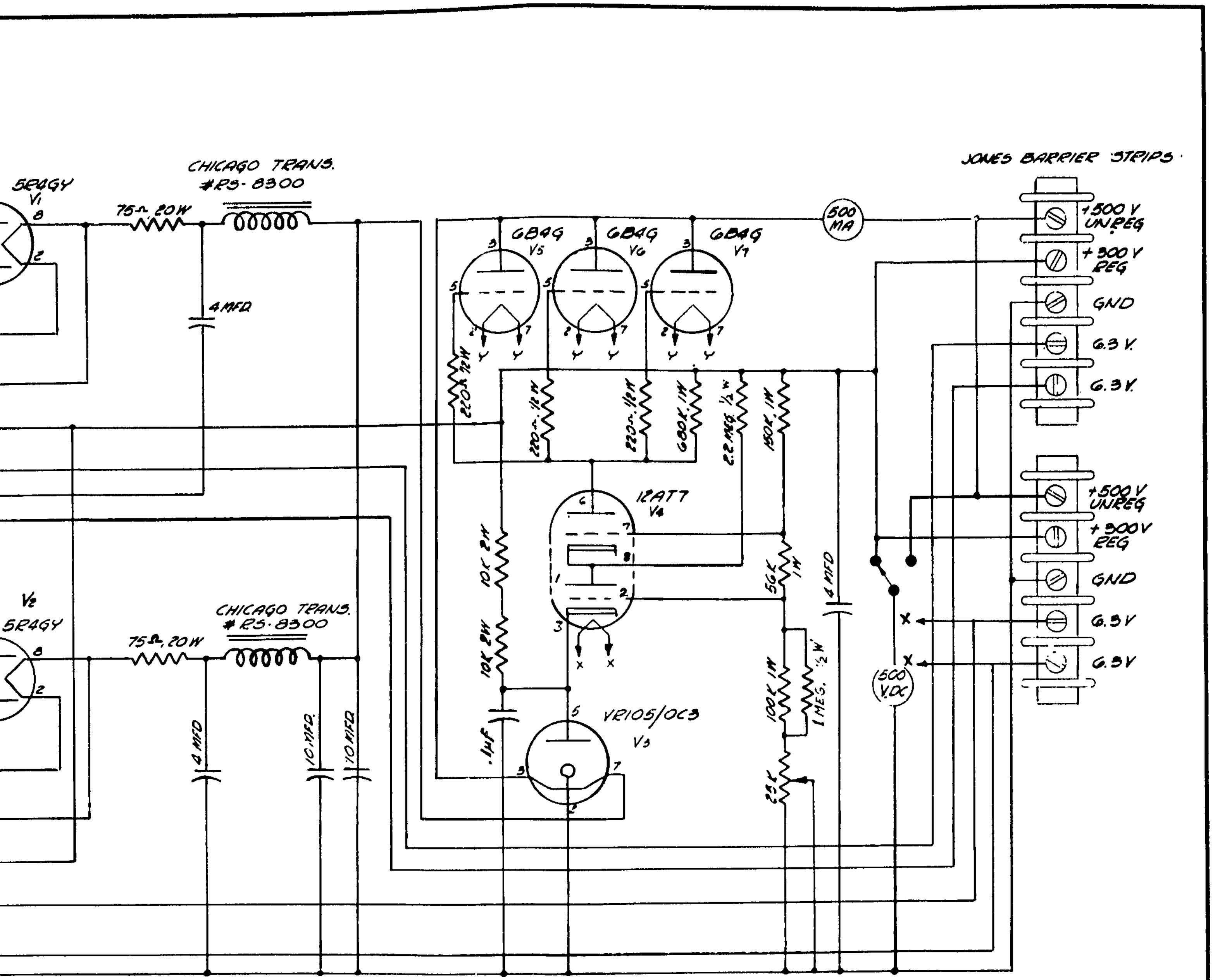
Drawing C-1554 Schematic of blanking circuit


6BQ7-A
.01 MFD
2.5 meg
33K
20K
1000 μμf
68 μμf
270K
V3
V2a
V2b
1meg
0.1 MFD
27K
110K
27K
GE 7472408
47 μμf
47 μμf
80 μμf
100K
150K ½W
V1a
V1b
10K ½W
MFD 0.1
120K 1W
12K ½W
240K 1W
6BQ7-A
1



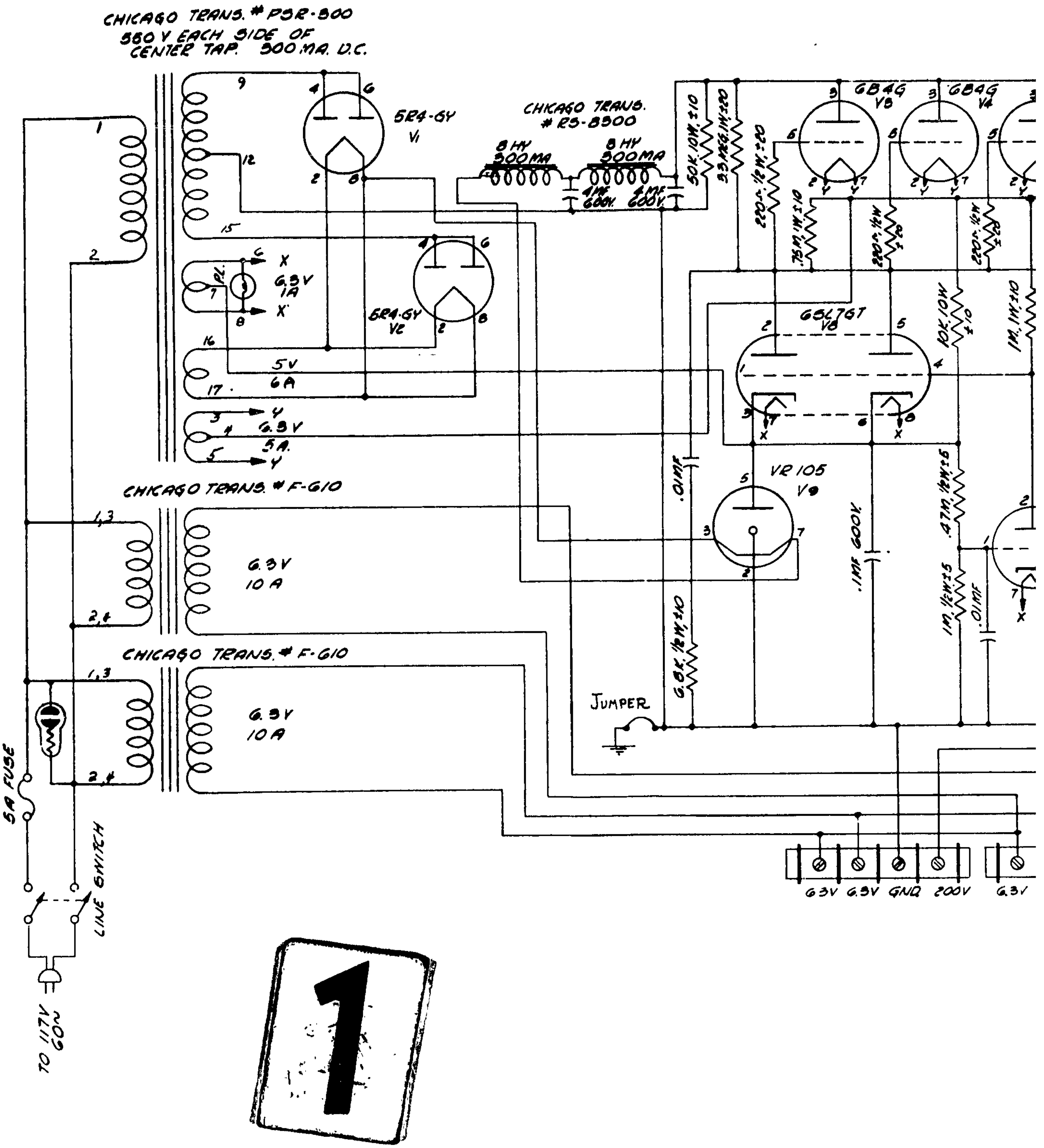
Drawing EX-21339 Schematic of lamp pulser


CHICAGO TRANS.
#PSR-300
550
550
5V.
6.3V
1A
6.3V
5A.
5R4GY
V1
75Ω 20W
CHICAGO TRANS.
#RS-8300
4 MFD
6B4G
V5
220Ω-1/2W
10K 2W
10K 2W
.1μF
V2
5R4GY
4 MFD
10 MFD
10 MFD
10 AMP
LINE SWITCH
TO 117 V 60~
1

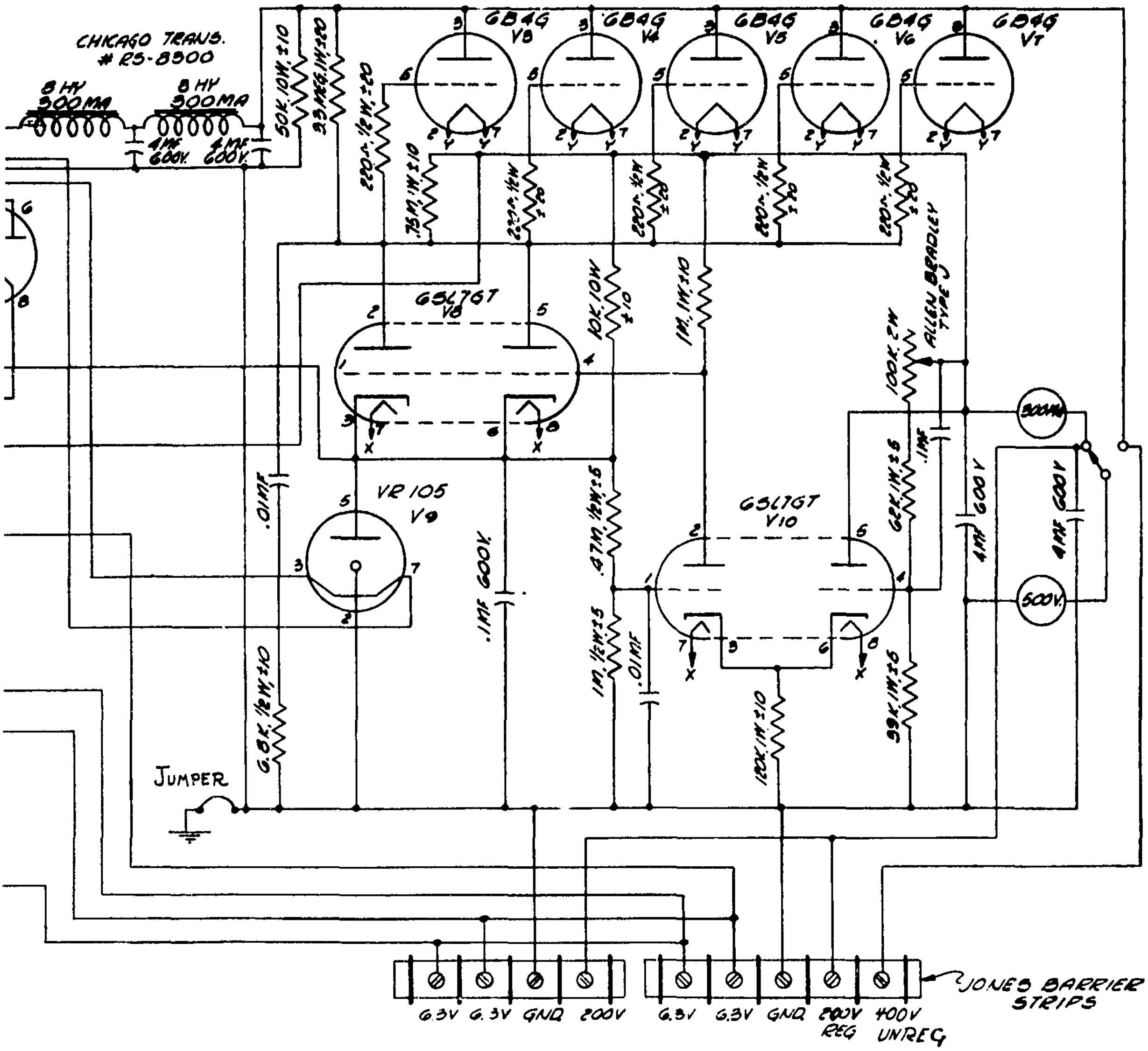


2

Drawing C-1308 Schematic of sweep power supply

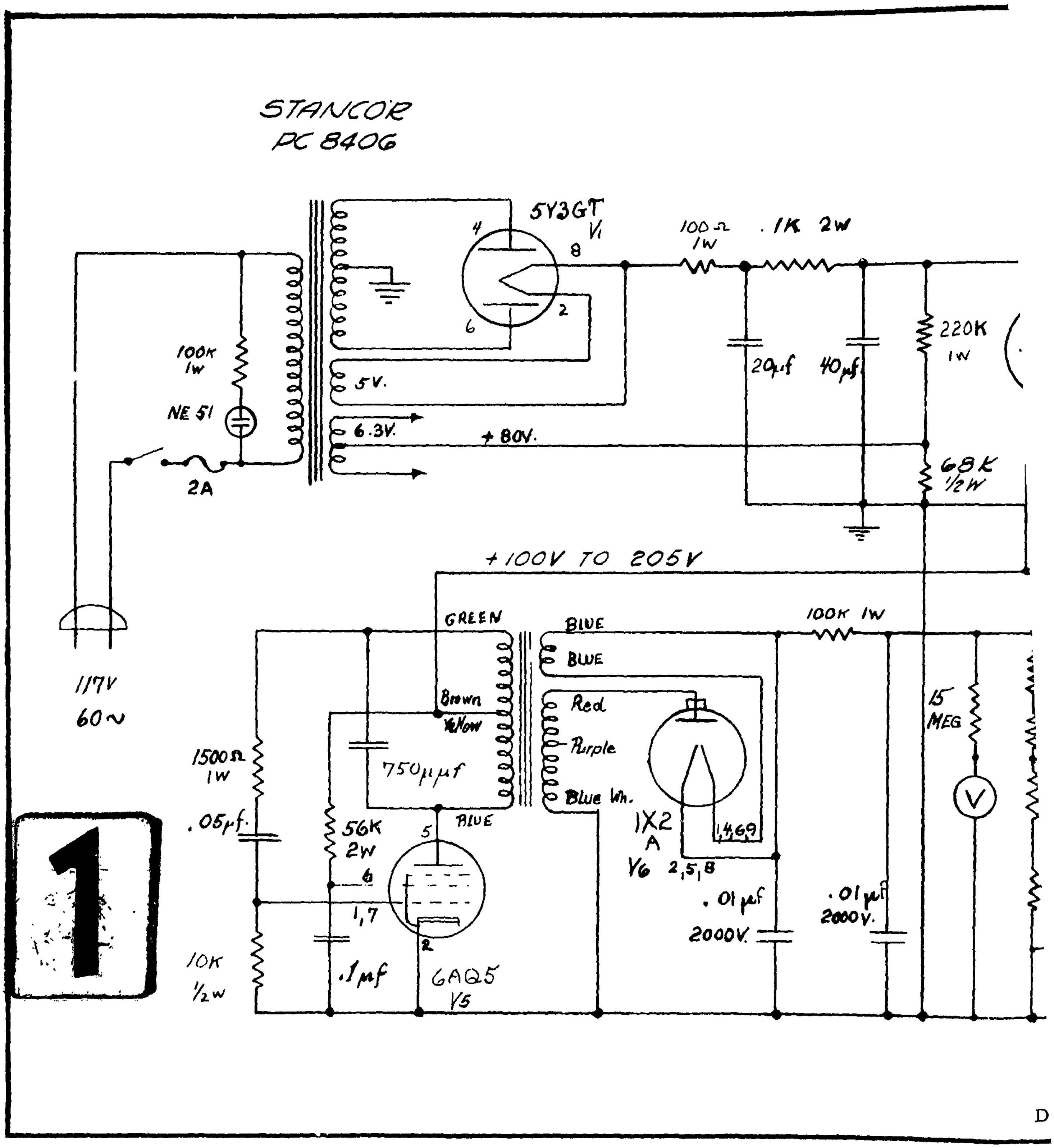


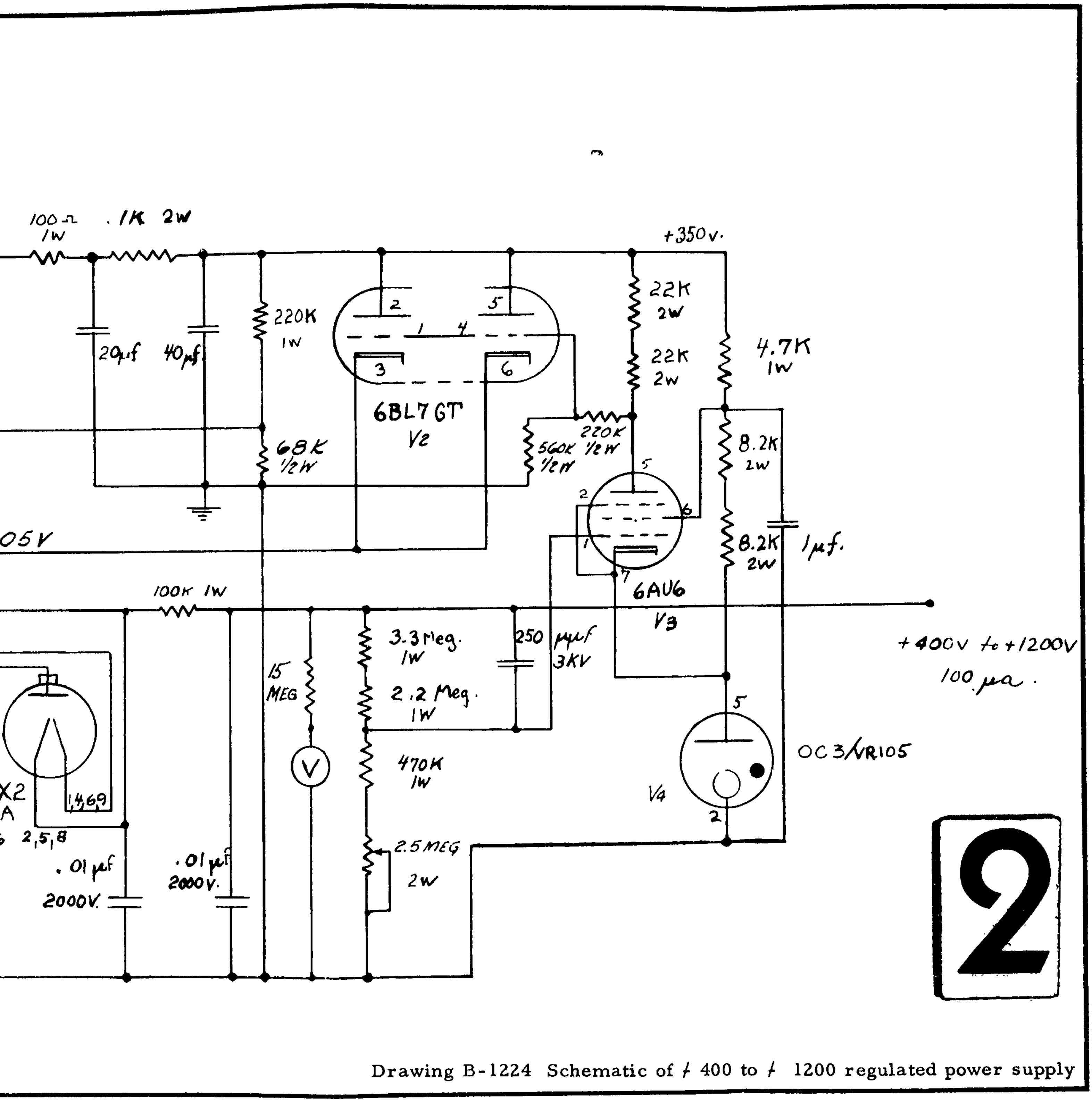
Drawing C-1235 S



2

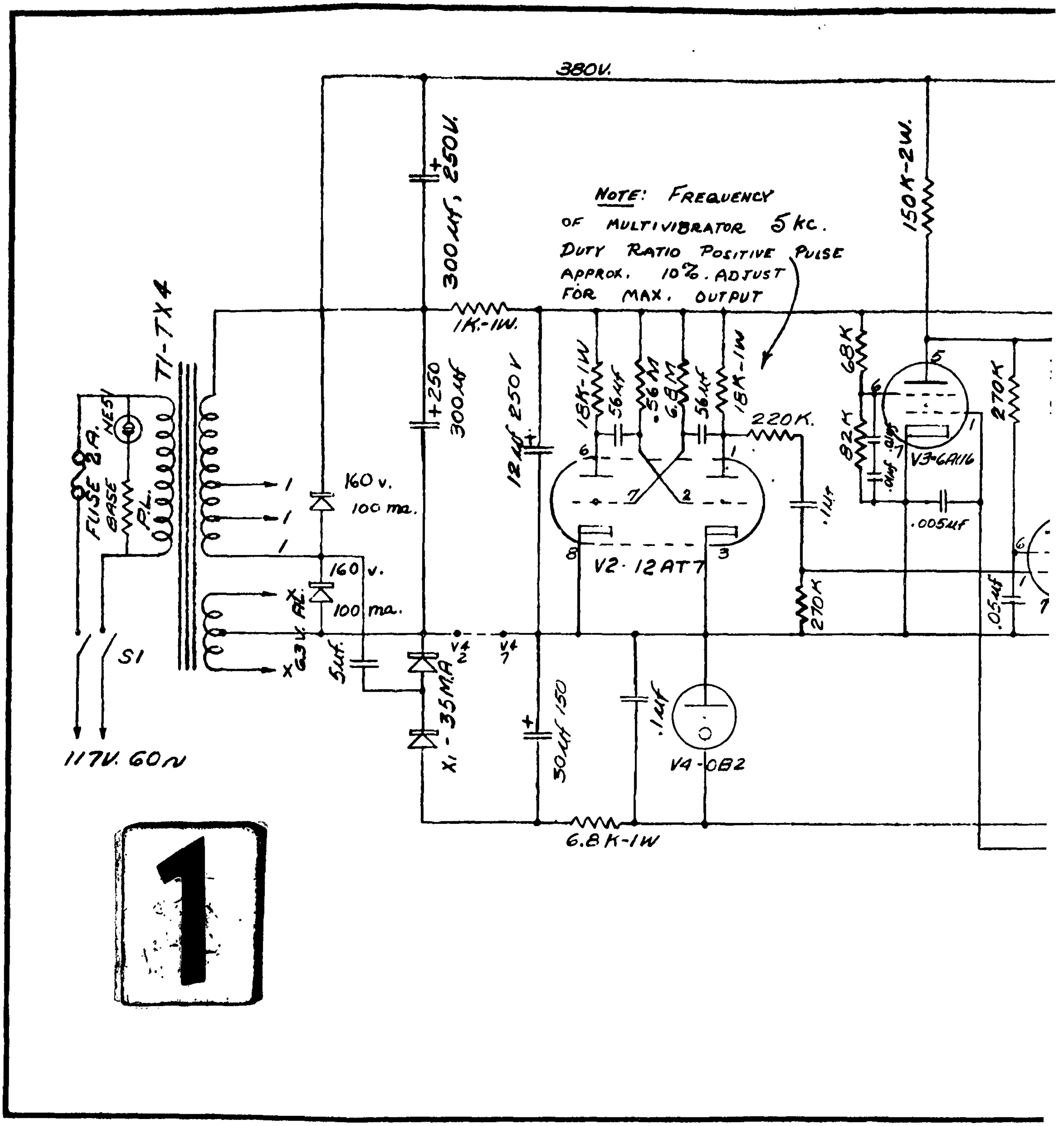
Drawing C-1235 Schematic of synchronizer and shaper power supply

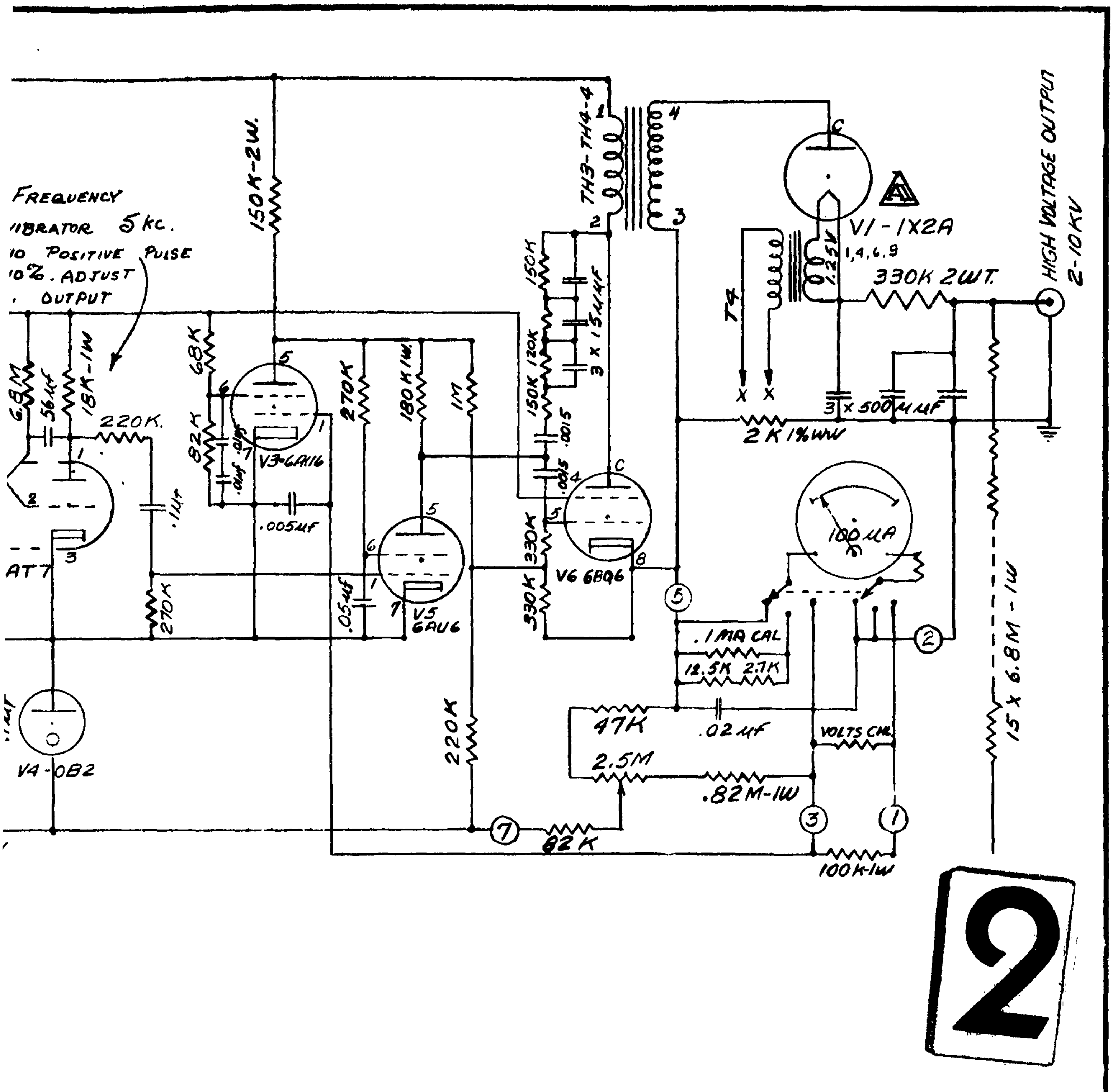

STANCOR
PC 8406
5Y3GT
V_1
100Ω 1W
.1K 2W
220K 1W
20μf
40μf
68K ½W
100K 1W
NE 51
5V.
6.3V.
+80V.
2A
+100V TO 205V
117V
60~
GREEN
BLUE
Brown
Yellow
Red
Purple
Blue Wh.
750μμf
1500Ω 1W
.05μf.
56K 2W
10K ½W
.1μf
6AQ5
V5
1X2
A
V6
2,5,8
1,4,6,9
.01μf 2000V.
100K 1W
15 MEG
1
D



2

Drawing B-1224 Schematic of + 400 to + 1200 regulated power supply


380V.
300µf, 250V.
150K-2W.
NOTE: FREQUENCY OF MULTIVIBRATOR 5 KC. DUTY RATIO POSITIVE PULSE APPROX. 10%. ADJUST FOR MAX. OUTPUT
T1-TX4
FUSE 2A.
NE51
BASE
P.L.
1K-1W.
+250 300µf
12µf 250V
18K-1W
56µf
.56M
6.8M
18K-1W
220K.
68K
82K
270K
V3-6AU6
.005µf
V2 12AT7
160 v. 100 ma.
160 v. 100 ma.
6.3V AC.
5µf.
X1 - 35 M.A
30µf 150
.1µf
V4-OB2
270K
.05µf
S1
117V. 60~
6.8K-1W
1



Drawing B-1060 Schematic of 8 KV regulated power supply

UNCLASSIFIED

The Rauland Corp., Chicago, Ill. HIGH SPEED SHUTTER SYSTEM by William O. Reed. December 1961. 114 p. incl illus. (Project 7065; Task 70824) (Contract AF 33(616)-2095).(ARL 175)

Unclassified Report

A high speed camera system of recording 16 pictures, each exposed to the light from the object being viewed for 3×10^{-7} to 3×10^{-6} seconds, was developed during the contract period. The system is capable of doing this with an overall light gain so that considerably less light need illuminate the object under study than is required by high speed camera systems based on other physical laws. The experimental evidence

(over)

UNCLASSIFIED

UNCLASSIFIED

furnished shows that photographic negatives having densities of 0.5 can be achieved with 1 microsecond exposure and 200 foot-candles illumination incident on the photocathode (150 watt projection lamp at 110 V) with readily available photographic film and camera optics.

UNCLASSIFIED

UNCLASSIFIED

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(over)

UNCLASSIFIED

UNCLASSIFIED

furnished shows that photographic negatives having densities of 0.5 can be achieved with 1 microsecond exposure and 200 foot-candles illumination incident on the photocathode (150 watt projection lamp at 110 V) with readily available photographic film and camera optics.

UNCLASSIFIED